TION BULLETIN 482

APRIL 1964

Marketing New England Poultry

5. Effects of Firm Size and Production Density on Assembly Costs

By

William F. Henry and Clark R. Burbee

AGRICULTURAL EXPERIMENT STATION
UNIVERSITY OF NEW HAMPSHIRE
DURHAM, NEW HAMPSHIRE

in cooperation with

Agricultural Experiment Station, University of Massachusetts
and Marketing Economics Division, Economic Research Service,
United States Department of Agriculture

TION BULLETIN 482 APRIL 1964

Marketing New England Poultry

5. Effects of Firm Size and Production Density on Assembly Costs

By
William F. Henry and Clark R. Burbee

AGRICULTURAL EXPERIMENT STATION
UNIVERSITY OF NEW HAMPSHIRE
DURHAM, NEW HAMPSHIRE

in cooperation with

Agricultural Experiment Station, University of Massachusetts
and Marketing Economics Division, Economic Research Service,
United States Department of Agriculture

This is part of a Northeast Regional Project, NEM-21 "Adjustments Needed in Marketing Northeastern Poultry Products," a cooperative study involving Agricultural Experiment Stations in the Northeast Region and supported in part by regional funds and funds from the Economic Research Service, United States Department of Agriculture.

Preface and Acknowledgements

This report is the fifth in a series being issued by the Agricultural Experiment Station, University of New Hampshire in cooperation with the Agricultural Experiment Station, University of Massachusetts and the Economic Research Service, United States Department of Agriculture. All three agencies contribute personnel, funds, or both to the several phases of this research program.

The series of reports is concerned with the economics of the poultry industry in New England. Previous publications in the series with their New Hampshire Experiment Station Bulletin Numbers are: 1. Characteristics of the Processing Industry (444). 2. Economies of Scale in Chicken Processing (459), 3. Capital Accumulation Potential of Broiler Growers (475), and 4. Structure and Performance of the Assembly System (476). Reports in process include 6. Economies of Scale in Broiler Chick Hatching and Costs of Chick Distribution, and 7. Economies of Feed Mixing and Distribution. Two companion reports published by the Agricultural Experiment Station, University of Massachusetts are: Freight Rates on Feed, Central Territory Origins to New England and the Middle Atlantic States (508) and Freight Rates and the Eastern Poultry Industry (533).

The authors acknowledge the contributions made to this analysis by Dr. Richard A. Andrews, University of New Hampshire. Professor Alfred A. Brown, University of Massachusetts and Mr. George B. Rogers, Economic Research Service, U. S. Department of Agriculture were intimately involved with the planning and conduct of the research reported in this bulletin including critical review of the manuscript.

TABLE OF CONTENTS

Summary

This report presents a synthetic analysis of space relationships designed to determine the net effects on assembly costs of change in 1) firm size, 2) supply density, and 3) transport distance. All other possible variables such as production and assembly technology, and bird type were kept constant.

Capacity of firms is specified in terms of 3.5 pound live birds hauled per day. Numbers of men and trucks required by any firm vary in this analysis to achieve the least cost combination for any assembly operation. Density is specified as the quantity of broilers produced in some two dimensional portion as the supply area (square mile) over some period of time (year). Three density levels: 1,000, 5,000, and 25,000 pounds of live broilers per square mile per year are considered in this study.

The synthetic model assumes a flat plane surrounding a center in a circular pattern with poultry located evenly over it. The model consists of a set of six such planes for each density level, one plane for each size of firm. In the analysis of the model the six planes are superimposed concentrically resulting in a single surface made up of six bands. Each band is the supply area added when moving from a smaller to a larger alternative firm size. Within each band poultry for any one day's pickup is assumed to be concentrated at an impound point so there is no travel between farms by pickup crew.

The sizes and numbers of crew-truck complements to achieve minimum labor imput for each plant size (at each density level) are determined from assembly matrices. These matrices handle all possible combinations of crew sizes (from three to ten men) and truck numbers. The diagonal of each lists various complements to be considered in assembling poultry in each supply band when the appropriate supply bands are handled separately by each firm. The upper right-hand half of each matrix lists the complements when considering combining assembly in two or more supply bands by any firm. The lower left-hand portion of each matrix is not applicable.

Costs of assembly were developed by applying appropriate cost rates to the physical input quantities determined from the matrix. Costs were developed for labor, management, truck ownership and operation, shrinkage, and crates at the three density levels for the six firms. Assembly costs per pound increase at each density level as size of firm increases: costs decrease at each firm size as density increases; and costs increase at each density level as hauling distance increases.

As assembly firm size increases from 4.15 million pounds per year to 69.16 million pounds assembly costs increase from 0.64 cents per pound of live birds to 0.92 cents at the 5,000 pound density level. For less dense production situations costs rise much more rapidly as size of firm increases, for more dense situations costs rise at a slower rate.

Production density has a marked effect on assembly costs. For Firm D (34.58 million pounds per year) costs fall from 1.26 cents per pound of live broiler at the 1,000 pound density level to 0.56 cents at the 25,000

pound density level. Changes in production density cause greater absolute and percentage changes in assembly costs for large firms than for small.

As hauling distance increases, the costs of assembly also increase. At the 5,000 point density level assembly costs increase almost 0.30 cents per pound when hauling distance increases from 20 miles to 80 miles.

Combining the costs of processing and assembly develops a more complete picture of marketing costs than either of the enterprises taken separately. This is because assembly costs per pound rise and processing costs per pound fall as firm size increases. By combining the costs of both enterprises the optimum firm size for each enterprise will be where minimum combined costs of both occur. For the 1,000 pound per year density level minimum costs of both combined are 4.09 cents per pound at the 26 million pound per year size. For the 5,000 pound density level, combined minimum costs are 3.56 cents at the 70 million pound size. For the most dense situation (25,000 pounds) minimum combined costs were not reached in this study, but had about leveled off at 3.30 cents for firm size of 70 million pounds.

Marketing New England Poultry

5. Effects of Firm Size and Production Density on Assembly Costs

By

William F. Henry and Clark R. Burbee[1]

I. Introduction

The purpose of this study is to determine the net effects on broiler assembly costs of changes in the size of assembly firms and in the density of broiler production. Such information can then be used by current or prospective commercial assemblers in their business decision making.

A previous study in this series described the structure and performance of the broiler industry in New England as it now exists.[2] It indicated that (1) most of the poultry is assembled by large commercial firms, (2) the assembly of most of the poultry is done or contracted by firms that have decision-making powers over placement of chicks and time and location of processing, (3) the small "old type" firms are steadily losing out to the large "newer type" firms, (4) some small live poultry dealers and slaughterers have specialized and limited markets to which they can profitably cater at high prices, and (5) the large commercial assemblers operate in the areas of high broiler production density. Because of this set of conditions, the analysis showed that the performance of firms in labor and truck productivity improved with increased size of firm; and consequently, that hauling costs per pound dropped as firm size increased. This is understandable because the larger firms in the New England region assemble from commercial broiler growing areas where density of broiler production is high.

If firms face the same production density in the broiler supply areas from which they assemble, then as firm size increases and other factors remain constant the costs of assembly per pound should also increase. This increased cost will be due to the influence of the greater distances

---

[1] Respectively Agricultural Economist, Agricultural Experiment Station, University of New Hampshire and Agricultural Economist, Animal Products Branch, Marketing Economics Division, Economic Research Service, U. S. Department of Agriculture stationed at the University of New Hampshire.

[2] G. B. Rogers and E. T. Bardwell, MARKETING NEW ENGLAND POULTRY, 4. *Structure and Performance of the Assembly System*, University of New Hampshire, Agricultural Experiment Station Bulletin No. 476, April, 1963.

over which birds need to be hauled. Similarly, as density of broiler production increases for firms of the same size the assembly cost per pound should decrease, because hauling distances will be reduced.

These two characteristics of the broiler assembly operation — size of assembly firms and density of broiler production — have independent effects on broiler assembly costs. A cross-sectional analysis of the actual assembly industry as was done in the previous study mentioned above does not fully separate out these two characteristics. Yet, the net effect of each on broiler assembly costs should be determined to provide decision-making data for assembly firm operations.

A research method designed to accomplish this is the synthetic development of model firms and their operation "on paper" to establish costs.[3] This method is quite similar to that used by engineers in designing buildings and plant layouts. In this report it consists of combining the elements of the assembly function in a logical way to arrive at cost descriptions of the model firms. Input requirement for the several phases of the assembly function are developed separately. These input requirements are based on technical coefficients, such as labor required to pick up poultry. These coefficients are derived from several sources, particularly surveys. Appropriate cost rates are then applied to the physical input quantities to establish a function relating output and costs.

This research method is used for the following reasons: (1) each firm is designed to handle a certain volume, (2) capacity as a concept is kept constant between firms, (3) each firm uses the technology appropriate to its size, and (4) fixed element valuation in firms can be kept consistent and not dependent on actual firm accounting procedures.

By use of the synthetic method in this study of broiler assembly, the results can be combined with those of the processing plant study already completed.[4] This will provide more complete information to the industry than if each of these enterprises is considered separately.

Assumptions and Conditions

Six model assembly firms of various capacities were developed to examine the effects on assembly costs of changes in the characteristics of firms. Records from 75 firms and information from equipment manufacturers and other sources helped determine organizational features, facilities, equipment, and technical production coefficients for the model firms.

The model firms are considered to be independent firms or autonomous divisions of firms carrying on other activities such as processing broilers or distributing feed. The organization of each model firm includes management and office functions as well as the picking up and hauling of poultry. Building space necessary to provide facilities for unloading and for crate storage is considered to be part of the processing plants. Office space is assumed to be rented.

---

[3] This research method is described in R. G. Bressler, "Research Determination of Economies of Scale," *Journal of Farm Economics*, Vol. XXVII, No. 3, August, 1945.

[4] G. B. Rogers and E. T. Bardwell, MARKETING NEW ENGLAND POULTRY, 2. *Economies of Scale in Chicken Processing*, University of New Hampshire, Agricultural Experiment Station Bulletin No. 459, April, 1959.

The cost budgets for the several sizes of model firms are based in part on the following assumptions and conditions:

(1) Only the effects on costs of changes in firm size and production density are studied, so other variables such as type of poultry house, factor productivities in broiler production, and type of bird are kept constant.

(2) The basic technical coefficients needed to determine the cost of assembly are:

(a) Effect of crew size on pickup rate,

(b) Effect of distance on travel time, and

(c) Effect of time in crates on live bird shrinkage.

(3) Hauling volume of model assembly firms is defined by the size of processing plants established in a proceeding report in this series.[5]

(4) The work day of truck drivers, pick up labor, and crew foremen, including productive time, off time, and travel time, cannot exceed 10 continuous clock hours. This is the typical maximum work day in the industry according to the survey of firms.

(5) Density is considered to be the quantity of 3.5 pound live weight broilers produced in some two dimensional portion of the supply area (square mile) over some specified period of time (year). Three levels of density are studied: 1,000, 5,000, and 25,000 pounds of live weight broilers produced per square mile per year. These include the range of density levels existing in New England.

(6) The assembly function is geared to the processing function so that no birds arrive at the processing plant prior to its opening, and the last load arrives at the plant in sufficient time so that it can be unloaded and processed before the plant closes. Processing plants generally operate for one shift per day covering nine clock hours. This relationship of the assembly and processing functions makes a second shift for assembly unnecessary.

(7) Poultry is located uniformly over the supply area, in predetermined flock sizes. Each flock has one age class, and each farm produces five flocks a year. A flock will be picked up within two consecutive work days.

(8) The work year of the firms is 247 days. This is made up of 52 five day weeks minus 13 paid holiday and vacation days. This corresponds exactly to the work year specified for the processing plants in a previous study in this series.[6]

(9) All poultry is picked up at the farms by crews of men that travel to the farms and back in cars. No pickup labor or foremen travel in the trucks.

(10) An exclusive supply area is assumed for each model firm. However, whether competition exists within an area makes little difference. Here, as in actual competitive situations, it is the production den-

---

[5] *ibid.*

[6] *Ibid.*, p. 8

sity achieved by the firms which affects its costs, not the total density of the area.

II. Technical Coefficients in Broiler Assembly

Location of Broiler Growing Units

1. Supply Plane

A model was developed that assumes a circular broiler supply area surrounding a center at which are located all facilities associated with the broiler industry. The birds are grown on farms uniformly dispersed over the supply area. The road network servicing these farms forms a uniformly spaced pattern of straight spokes radiating from the center with lateral roads, concave to the center, connecting these main roads.

The basic physical characteristics of the model are shown in Figure 1 for a production density of 5,000 pounds of live broilers per square mile per year.[1] A set of six model firms ranging in size from 4.15 million pounds per year to 69.16 million pounds per year were established, and are listed in Table 1. The six supply bands drawn in Figure 1 are of unequal widths because the sizes of these assembly firms were set to agree exactly with the sizes of six of the firms used in the processing plant report. Each of the six supply bands drawn in Figure 1 shows the size of the supply area added when moving from one size of firm to the next larger size. Thus, the supply band designated I is the supply area for Firm A. The supply band designated II is the supply area added to the supply area of Firm A to make up the whole supply area for Firm B.

Each of the supply bands indicated in Figure 1 is considered to be a separate entity in that each band will produce during some time period a specified quantity of poultry. Table 1 shows these quantities on a yearly and daily basis. Band I on each collection day (5 days per week generally) yields 4,800 broilers of 3.5 pounds each, Band II on each collection day yields 9,600 broilers, and so on. Each of the supply bands has the quantity of poultry ready for collection on a daily basis as indicated in Table 1. As an example, Firm C has to assemble 28,800 birds a day over its whole supply area. But it is specified that Firm C has to pick up these birds from three separate locations: 4,800 from Band 1, 9,600 from Band II, and 14,400 from Band III. Figure 1 must be visualized as a set of six superimposed concentric discs, each disc being a separate model firm and showing that each firm must collect from each supply band included within its supply area.

2. Impound Points

Poultry is picked up each work day from each band into which the size of the firm permits it to go. For instance, Firm C will not assemble beyond Band III. Inside each band the poultry ready to be collected each day is "impounded" at one point. This means that birds for any one day's pickup are not scattered around in small flocks, but are located in one flock or impound point. The number of birds located at the im-

---

[1] Further described in Appendix C along with the 1,000 and 25,000 pound density levels.

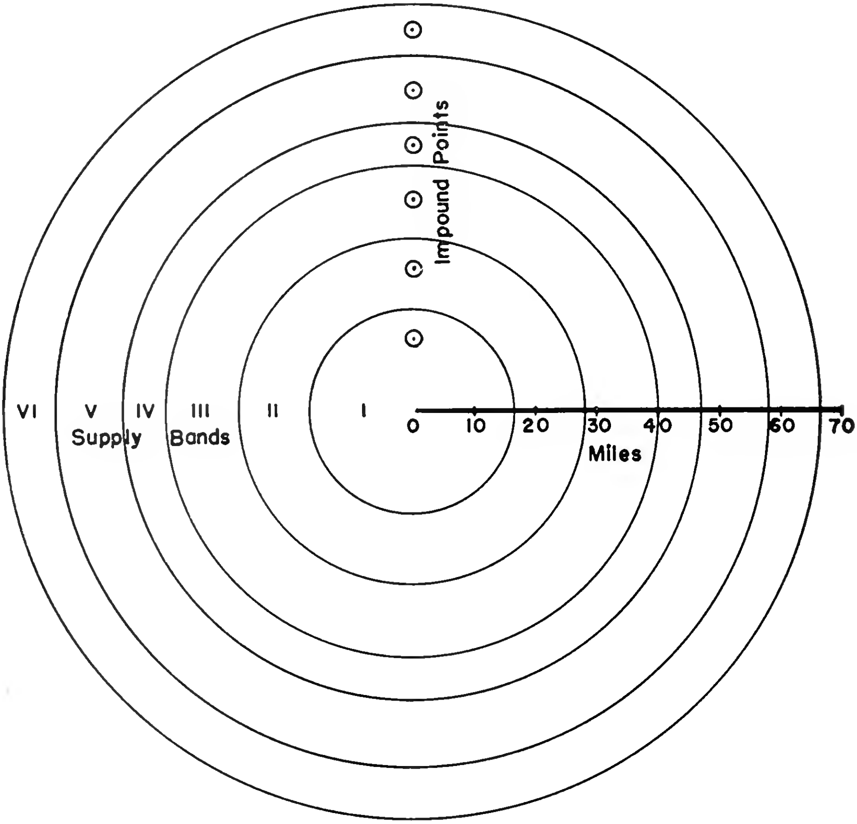
Table 1. Volume Characteristics of Six Model Assembly Firms

	Annual Volume*			Daily Volume*			Daily Truck Loads†	
	Pounds (million)	Birds (million)	Crates (thousand)	Pounds (thousand)	Birds (thousand)	Crates (number)	220 (number)	190 (number)
Band				*Band Totals*				
I	4.15	1.19	79.0	16.8	4.80	320.0	1.45	1.68
II	8.30	2.37	158.1	33.6	9.60	640.0	2.91	3.37
III	12.45	3.55	237.2	50.4	14.40	960.0	4.37	5.05
IV	9.68	2.77	184.4	39.2	11.20	746.7	3.39	3.93
V	17.29	4.94	329.3	70.0	20.00	1,333.3	6.06	7.02
VI	17.29	4.94	329.3	70.0	20.00	1,333.3	6.06	7.02
Firm				*Firm Totals*				
A	4.15	1.19	79.0	16.8	4.80	320.0	1.45	1.68
B	12.45	3.56	237.1	50.4	14.40	960.0	4.36	5.05
C	24.90	7.11	474.3	100.8	28.80	1,920.0	8.73	10.10
D	34.53	9.88	658.7	140.0	40.00	2,666.7	12.12	14.03
E	51.87	14.82	988.0	210.0	60.00	4,000.0	18.18	21.05
F	69.16	19.76	1,317.3	280.0	80.00	5,333.3	24.24	28.07

* Based on 3.5 pound live weight broilers, 15 broilers per crate, 52.5 pounds per crate.

† In terms of trucks with load capacities of 220 crates or 190 crates.

Figure 1. Supply Plane for Broilers Showing Superimposed Supply Areas of Six Model Firms, and Supply Bands Added as Firm Size Increases, 5,000 Pounds Per Square Mile Per Year Density Level.



pound point in each supply band is shown in Table 1. For any work day this is also the number of birds of market weight located anywhere in the band, so specifies the maximum flock size that can exist in any particular band.

This condition is relaxed somewhat by the assumption mentioned earlier that a flock of one-aged birds can be as large as the quantity that will be picked up from a given band in two days. So the maximum size of flock allowed in terms of one age group of birds is: Band I – 9,600, Band II – 19,200, Band III – 28,800, Band IV – 22,400, and Bands V and VI – 40,000. These numbers also specify the maximum number of birds of a given age group allowed in the whole of each band. With this designation of impound points no inband travel between farms is considered. Assuming that there are 247 days during the year when poultry is assembled and each farm produces five flocks per year, there will be about 50 possible impound locations in each band.

The location of the impound point in each band bears a relationship to the radius of the band. The impound point will be located in

each band someplace between 70.71 percent and 50 percent of the distance from the inner edge of the band to its outer edge.[2] This is the "average" location of the poultry in the band. The locations of the impound points are indicated in Figure 1. The radial distance of the impound point in any supply band from the plant is the full radius of the next smallest supply area plus the distance into the supply band for that impound point.[3] The locations of the several impound points from which any individual firm assembles poultry on any particular day are all along the same radial line from the plant. This arrangement permits the analysis of movement of crews between impound points, while at the same time meeting the requirement for no travel within bands, and minimizing travel between impound points in different bands. Locations of impound points along such a radial line is illustrated in Figure 1. During a year there will be about 50 positions around the supply plane for this radial line.

Constructing the assembly model with this type of band and impound point arrangement facilitates the development of crew-truck combinations for the assembly job. The band and impound point arrangement simplify (1) setting up the precise timing and arrangement of trips, (2) indicating how many of the trucks can pick up one load a day and how many more than one load, and consequently, how many trucks are needed, (3) indicating numbers of crews needed and their sizes, and (4) determining whether trucks can reach the perimeter of a supply area within the restrictions of the model. One average location of poultry for each sized firm cannot accomplish these needs of the study.

Truck Productivity in Live Bird Transportation

The number of loads for trucks of two sizes needed to assemble the poultry from each band is indicated in Table 1. The most typical sizes of trucks used by assembly firms can handle 190 or 220 crates, so these were the sizes chosen.

Trucks are assumed to leave from plants at the beginning of each work day and make as many round trips as is possible within the restriction that the work day cannot exceed 10 consecutive hours. No second shift is permitted as indicated in Assumption 6.

It was necessary to determine the hauling distance for poultry from the impound points to the plants, and to determine truck and car travel distances. To do this, the relationship between road distances and radial distances under New England conditions was established.[4] For all radial distances greater than 10 miles a linear regression equation was used:

$$D = -1.534 + 1.351P$$

Where:

D = road distance in miles

P = radial distance in miles

For radial distances less than 10 miles the following linear regression equation was used:

$$D = 1.196P$$

---

[2] See Appendix A.

[3] See Appendix Table F-1.

[4] See Appendix A.

The time involved in travel for trucks and crews was considered to be entirely associated with mileage, but the longer the trip the greater the average speed per mile. The relationship between trip length and travel time and the method of converting radial distances to travel time are given in Appendix B. Travel speed for either size of truck is the same and depends upon the one-way trip distance.

The density of production in the supply area, the size of the pickup crew, the volume to be hauled, the miles involved in hauling, and the restriction of a 10-hour work day all interact to establish the maximum distance poultry can be located from the plant, and the number of trips a truck can make in one day. Appendix C develops this relationship. The less dense the production of poultry in any firm's supply area, the greater the distances trucks must travel to assemble a given volume, and the fewer the number of trips a truck can make.

Labor Productivity in Loading Live Birds

The loading activity at the farm consists of: positioning trucks, setting up catching pens, catching and carrying the birds, placing the birds in the crates on the truck, and securing load. Labor productivity coefficients for live bird loading are essential data in the use of the assembly model for quantifying input requirements. Observation of assembly operations and records of assembly firms were used in determining these coefficients. Labor use is divided into two categories: travel time from plant to farm and return, and loading time at the farm. The former is essentially "overhead" time for the pickup job involved; the latter is variable in that it depends upon the quantity of poultry.

The men involved in the assembly function are divided into three classifications: truck drivers, pickup labor, and foremen. One truck driver is assigned to each truck. Each round trip of a truck consumes an amount of driver time equal to the elapsed time from plant and return to plant for one driver. This includes loading time of his truck at the farm, but not unloading time at the plant. If the truck makes more than one trip, turn-around time at the plant is included with driver time.

One foreman is assigned to each crew. Foreman time is the amount of elapsed time from plant and return to plant for the crew, which includes the amount of time spent traveling, loading birds, and off time. Pickup labor time per crew in the assembly operation is the elapsed time from plant and return to plant for the crew multiplied by the number of pickup laborers per crew. This includes amount of time spent traveling, loading birds, and off time.

The loading crew includes a foreman, the driver of the truck which is being loaded, and a number of pickup laborers, all entering into the physical activities necessary for pickup and loading. The number of men in the crew will be such as to minimize labor use. The method of arriving at this is explained later. It depends upon travel distances, various sizes of crews, and the quantity of poultry that has to be loaded. The restrictions are that no pickup laborer, foreman, or truck driver can put in more than a 10-hour day from plant and back to plant, and that crew size cannot exceed 10 men (one foreman, one driver, eight laborers).

Data from actual loading operations in New Hampshire were used to determine the relationship of crew productivity to crew size. This is shown in Table 2 for crews ranging from three to 10 men. Appendix D further discusses the development of the coefficients.

Table 2. Labor Productivity in Loading Live Birds, by Crew Size, and Loading Time Required According to Truck Size

Crew Size*	Average Productivity Per Man Hour	Crew Productivity Per Hour	Loading Time Required Per Truck		Man Hours Required Per Truck	
			220 Crates	190 Crates	220 Crates	190 Crates
(men)	(pounds)	(crates)†	(hours)		(hours)	
3	563	32.2	6.83	5.90	20.49	17.70
4	732	55.8	3.94	3.40	15.76	13.60
5	834	79.5	2.77	2.39	13.85	11.95
6	895	102.0	2.15	1.86	12.90	11.16
7	929	123.9	1.78	1.53	12.46	10.71
8	945	144.0	1.53	1.32	12.24	10.56
9	949	162.9	1.35	1.17	12.15	10.53
10	942	179.0	1.23	1.06	12.30	10.60

* Includes driver of truck being loaded, foreman of crew, and pickup labor.
† Crates hold 15 broilers of 3.5 pounds each or 52.5 pounds.

Truck Unloading Time at the Plant

Unloading crates from trucks at the plant is carried out by the unloading crew at the plant. This crew is part of the processing plant labor force and is a cost to the processing plant. However, the time involved for unloading is a concern of the assembly firm, because the truck turn around time influences the number of trips a truck can make per day.

The unloading time is based on the speed at which crates can be taken off trucks, line speed of the plant, and speed at which empty crates can be reloaded and tied. Based on data from assembly operations, a one hour turn around time at the plant is assumed for a full load on a 220 crate truck. All other load sizes are proportionate to this.

Shrinkage of Live Birds in Assembly

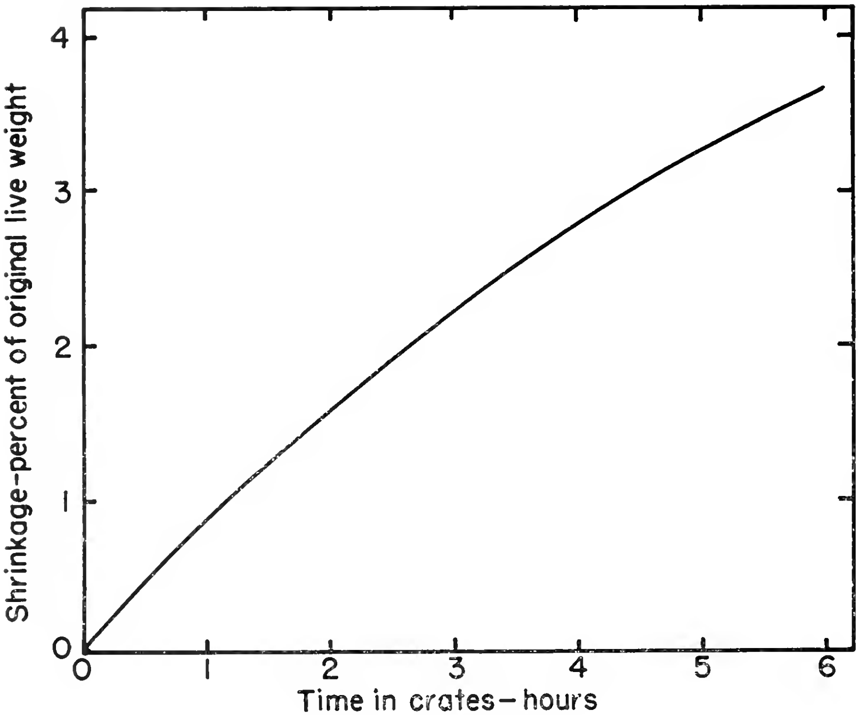
An important cost in assembly is weight loss of birds. This weight loss, or shrinkage, is primarily caused by the loss of water through transpiration. As time in transit increases, shrinkage increases at a decreasing rate. Moreover, it is apparently related to the time in crates rather than merely travel time. The time in crates for each load of poultry was determined by adding one-half of the loading time, the time in transit, and one-half of the unloading time.

The physical relationships used for shrinkage are taken from a study done at Connecticut.[5] King and Zwick developed three "commer-

[5] R. A. King and C. J. Zwick, COMPETITIVE POSITION OF THE CONNECTICUT POULTRY INDUSTRY, 4. *Shrinkage of Live Poultry Between Farm and Market,* Storrs Agricultural Experiment Station Bulletin No. 270, 1950.

cial" curves relating percent shrinkage to time. Because broilers are younger in age at selling weight today than in 1950, it was decided to use their high commercial shrinkage curve rather than the average. The curve used is shown in Figure 2.

Figure 2. Relationship of Shrinkage of Live Birds to Time in Crates.



III. Resources Required in Broiler Assembly

The Assembly Model

The objectives of this research are to determine for each of the assembly firms under each of the three density conditions (1) the least-cost complement of men and trucks required for each pickup operation and (2) the least-cost number of such complements required for the firm.[1]

The basic technical coefficients needed to determine the cost of assembly are labor productivity in loading birds, truck and car travel time, truck turn around time at the plant, and live bird shrinkage. These were

[1] Complement is the term applied to the men and trucks that go to each impound point and pickup, load, and transport the birds to the plant. More specifically it refers to the number of men in a pickup crew and the *loads* of poultry they handle, rather than trucks, because some trucks will be able to make more than one trip.

established in Section II and now must be used in the assembly model to determine the optimum use of resources to accomplish particular requirements in moving poultry.

The organizing of the assembly operation involves the following:

(1) The poultry located at any impound point will be loaded by a crew composed of a truck driver, a foreman, and a number of pickup laborers. This crew ranges from three to ten men.

(2) The trucks are scheduled in their arrival time at the farm so no truck has to wait to be loaded.

(3) The foreman and his pickup labor remain at a given impound point until all the poultry located there is loaded out. The crew then proceeds to the impound point in another band, or back to the plant.

(4) All personnel begin and end their work day at the processing plant, but the work day cannot exceed ten hours.

(5) Trucks make as many round trips as possible.

The least-cost set of resources (trucks and men) for each firm size at each density level was determined from an assembly matrix. Such an assembly matrix is shown schematically for Firm F in Figure 3. The upper left to lower right diagonal of the matrix handles the various quantities of resources required to assemble poultry from each supply band, when supply bands are taken separately. The upper right-hand portion of the matrix handles the resources required when considering combining assembly in two or more supply bands. Such combining becomes more economical as firms become larger and as production density becomes higher. Through this procedure it is possible to handle effects of firm size simultaneously with effects of distance. The lower left-hand portion of the matrix is not applicable.

1. Resources Required for Supply Bands

The steps, restrictions, and assumptions used to determine the least-cost set of resources required for each element along the diagonal of the matrix are:

(1) Each production density situation was considered separately.

(2) The set of resources will be made up of one or more complements of men and truck-loads of poultry.

(3) The trucks used in the analysis have 190 and 220 crate capacity. Each size of truck was tested for its impact on cost for each load of poultry.

(4) Labor time, truck size, truck numbers, and shrinkage are all substitutes for each other. As will be explained presently, substitution among them was tested in several ways to achieve the least-cost combination of all four.

(5) The least-cost set of resources (men and trucks) to assemble birds from the impound point in each supply band taken separately is first of all determined. At this stage in the procedure, firms as such are not being considered. That is, the elements on the diagonal in the as-

Figure 3. Schematic Diagram of Assembly Matrix.

Assembly Firm

		A	B	C	D	E	F
	I	1a	1b	1c	1d	1e	1f
	II		2b	2c	2d	2e	2f
Supply Band	III			3c	3d	3e	3f
	IV				4d	4e	4f
	V					5e	5f
	VI						6f

sembly matrix, such as 3c, are being handled. Each of these elements is a separate supply band.

(6) In each element on the diagonal in the matrix, all crew sizes ranging from three to ten men in combination with *each* possible number of loads were tested to determine the crew size using the least amount of labor time. This is the process of seeking dominance. For instance, if four loads are to be assembled, it is possible to use the following load numbers in complements: four one-load complements, two two-load complements, one four-load complement, and one one-load complement with one three-load complement. Each complement requires only one foreman. Smaller crew sizes generally exceeded the restriction of a 10-hour work day, so they were rejected as not feasible.

(7) Labor time involved in these computations included the travel time and off time for pickup labor and foremen and the loading time for pickup labor, foremen, and the driver of the truck being loaded. Travel time is an "overhead" time element increasing in total with size of crew and distance. Loading time is a "variable" time element decreasing in total with size of crew and having no relation to distance.

(8) The crew sizes using the least amount of labor for all load numbers in each element on the diagonal were compared and the crew-load complement using the least labor to assemble the poultry from the impound point for the supply band involved was determined and tentatively selected as the least-cost complement.

(9) Labor costs for the selected crew-load complement in each element were determined.

(10) The final procedure in dealing with the elements along the diagonal in the assembly matrix was to set up a time schedule or log for the crew-load complement tentatively selected for the following purposes:

(a) To determine which, if any, of the trucks could make more than one trip.

(b) To make sure unloading of trucks could be accomplished in time at the plant.

(c) Based on a and b, to reassess other crew-load complements to be sure that the one finally selected yielded the least *combined* cost of both labor use and truck ownership and was feasible as regards unloading time at the plant.

2. Resources Required for Assembly Firms

The supply bands exist only as parts of firm supply areas. For instance, the supply area for Firm C is made up of Supply Bands I, II, and III. Assembly of poultry from each supply band is only a part of the full assembly operation of the firm, so the crew-truck organization for each firm must be established. To do this, elements in the upper right-hand portion of each assembly matrix, such as the one shown in Figure 3, were developed.

Each firm can assemble from each band independently of the other bands, in which case the diagonal of the matrix applies. Or the firm can combine two or more bands in one assembly operation, so that the same loading crew works first at one impound point in one band and then at one in another band, in which case the upper-right hand portion of the matrix applies. So even though crew travel within a band is eliminated in this model, crew travel between impound points in different bands is permitted. This construction permits exactness in comparing alternatives; yet it recognizes that crew travel in the field can be done if conditions warrant it. Combining of bands was carried out only if this yielded lower cost. Research procedures for this stage were similar to those described above for supply bands.

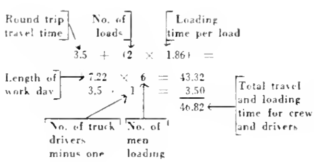
Substitution Among Resources

Four variables in the assembly operations, all resulting in important costs, are considered in these research procedures: total labor time, size of trucks, number of trucks, and shrinkage. These are related to each other in a substitution sense.

Trucks and labor substitute for each other; therefore, the cost of idle crew time at the farm waiting for a truck to return for reloading must be weighed against the additional cost of providing another truck. For instance, a crew of five pickup laborers and a foreman receive $7.31

Figure 4. Method of Determining Least Labor Cost Complement of Men and Loads to Assemble Supply Band III, 190 Crate Trucks, 5,000 Pound Per Year Density Level, 5.05 Loads.

Men	Loads 1	2	3	4	5	6
3	3.5 + 5.90 = 9.4 × 3 = 28.2					
	3.5 + (1.05 × 5.90) = 3.8 × 3 = 11.4†	3.5 + (1.05 × 5.9) = 9.7 × 3 = 29.1 3.5 × 1 = 3.3 32.6				
4	3.5 + 3.40 = 6.9 × 4 = 27.6†	3.5 + (2 × 3.4) = 10.3*				
	3.5 + (1.05 × 3.4) = 3.67 × 4 = 14.68	3.5 + (1.05 × 3.4) = 7.07 × 4 = 28.28 3.5 × 1 = 3.50 31.78†	3.5 + (2.05 × 3.4) = 10.47*			
5	3.5 + 2.39 = 5.89 × 5 = 29.45	3.5 + (2 × 2.39) = 8.28 × 5 = 41.40 3.5 × 1 = 3.50 44.90†	3.5 + (3 × 2.39) = 10.67*			
		3.5 + (1.05 × 2.39) = 6.01 × 5 = 30.05 3.5 × 1 = 3.50 33.55	3.5 + (2.05 × 2.39) = 8.40 × 5 = 42.00 3.5 × 2 = 7.00 49.00†	3.5 + (3.05 × 2.39) = 10.79*		
6		3.5 + (2 × 1.86) = 7.22 × 6 = 43.32 3.5 × 1 = 3.5 46.82	3.5 + (3 × 1.86) = 9.08 × 6 = 54.48 3.5 × 2 = 7.00 61.48†	3.5 + (4 × 1.86) = 10.94*		
			3.5 + (2.05 × 1.86) = 7.31 × 6 = 43.86 3.5 × 2 = 7.00 50.86	3.5 + (3.05 × 1.86) = 9.17 × 6 = 55.02 3.5 × 3 = 10.50 65.52†	3.5 + (4.05 × 1.86) = 11.03*	
7				3.5 + (4 × 1.53) = 9.6 × 7 = 67.2 3.5 × 3 = 10.5 77.7†		
				3.5 + (3.05 × 1.53) = 8.17 × 7 = 57.19 3.5 × 3 = 10.5 67.69	3.5 + (4.05 × 1.53) = 9.7 × 7 = 67.9 3.5 × 4 = 14.0 81.9†	
8				3.5 + (4 × 1.32) = 8.78 × 8 = 70.24 3.5 × 3 = 10.05 80.29	3.5 + (5 × 1.32) = 10.1*	
					3.5 + (4.05 × 1.32) = 8.85 × 8 = 70.80 3.5 × 4 = 14.00 84.80	3.5 + (5.05 × 1.32) = 10.17*
9					3.5 + (5 × 1.17) = 9.35 × 9 = 84.15 3.5 × 4 = 14.00 98.15†	
						3.5 + (5.05 × 1.17) = 9.41 × 9 = 84.69 3.5 × 5 = 17.50 102.19†
10					3.5 + (5 × 1.06) = 8.8 × 10 = 88.0 3.5 × 4 = 14.0 102.0	
						3.5 + (5.05 × 1.06) = 8.85 × 10 = 88.5 3.5 × 5 = 17.5 106.0

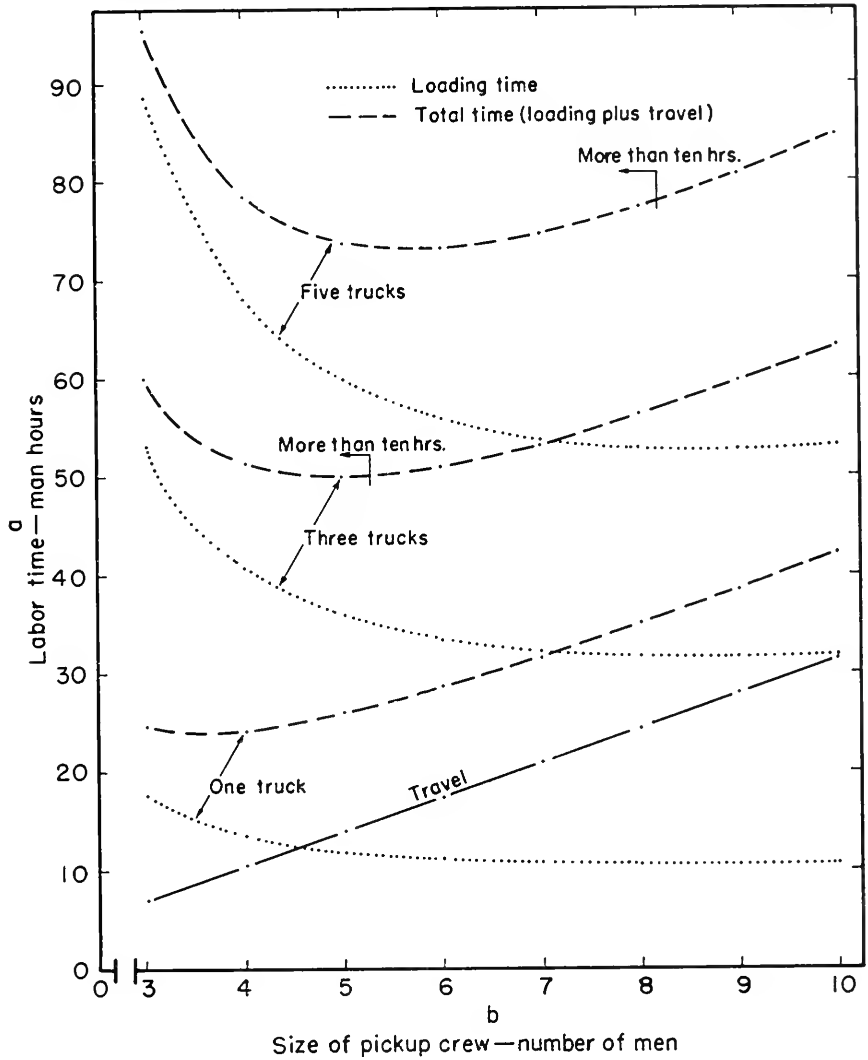


* Exceeds 10 hours.
† Least cost complement.

total wages per hour. The costs (excluding gasoline, oil, and tires) of owning one 190 crate truck is $6.47 per day. If the crew is idle more than 53 minutes per day waiting for a truck to return, it will pay to own another truck and have it at the farm when the crew is ready for it. This substitutes truck ownership costs for the cost of idle crew time. When considering such a substitution, the variable costs of truck operation, including gasoline, oil, tires, and driver time, are of course not considered. They remain the same because the number of birds hauled, and consequently the number of loads, remains the same.

Trucks and labor substitute for each other in another way, not involving "idle" time of the crew. Small crews load at a slower rate than large crews. If a small crew is used to assemble birds from a given im-

Figure 5. Illustrations of the Effects of Travel and Loading Time in Assembly, using a One-load Complement, a Three-load Complement, and a Five-load Complement, Band III, 5,000 Pound Density Level.



a. Excluding truck driving time.

b. In each case one foreman, one driver, and one to eight pickup laborers.

NOTE: This figure does not show total time required to assemble Band III.

pound point rather than a large crew, the total loading time will be greater. This increased loading time will tie up trucks for longer periods at the farm and reduce the opportunity for the trucks to make more trips per day. As the crew size increases, the number of man hours required in loading at the farm decreases. However, as crew size increases

so do the man hours of time devoted to travel. These man hours of travel time for the crew eventually increase faster than the man hours of loading time decreases. (See Figure 5). The larger the crew for any particular loading job, the faster the trucks can be loaded, and the larger the crew, the greater the man hours of crew travel time for any particular loading job. So trucks and crew travel time become substitutes for each other as crew size gets larger. The decision making problem involves comparing the cost of the unproductive time of crew travel for additional crew members against the reduction in truck ownership costs.

Another substitution relationship exists between shrinkage and crew size. Shrinkage can be controlled within limits by increasing or decreasing the size of the loading crew. This will change the length of time birds spend in the crates while the truck is still at the farm. For instance, if a four-man crew rather than a six-man crew is used to load a 190-crate truck (9,975 pounds of broilers), it will take 1.54 hours longer. This will result in additional shrinkage of 60 pounds. Valued at 16.0 cents per pound this costs $9.60. On this basis it would pay to use the larger crew until the unproductive round trip travel time of the fifth and sixth men cost $9.60 in wages. This would occur at a point 51.7 miles from the plant.[2] Truck size is a substitute for shrinkage, because the smaller the truck, with any given size of loading crew, the shorter the stay at the farm. Truck size will not influence labor costs in loading birds.

Example of Use of the Assembly Model

Assembly matrices, similar to the one shown schematically in Figure 3, were the basis for developing the least cost set of resources (men and trucks) needed to assemble birds for each of the firm size and production density situations. To illustrate the method used the following case is presented. This case is concerned with element 3c from Figure 3 for the 5,000 pound per year density level using 190 crate trucks. It involves the assembly of birds (14,400 birds or 960 crates) from Supply Band III with no reference to assembly of birds from any other band by Firm C. With 190 crate trucks this is equivalent to 5.05 loads, which requires six truck trips.

1. *Least Cost Complements*

Figure 4 shows the calculations for this case which were obtained in the following manner:

(1) The travel time required for the foreman and pickup labor to reach the impound point from the plant was determined (See Appendix B and Appendix Table F-1.) and doubled to obtain round trip travel time of 3.5 hours.

(2) Added to travel time was the time necessary to load the number of loads specified horizontally in Figure 4. The loading time per load

[2] At a wage rate of $1.26 per hour for pickup labor, the $9.60 represents 7.62 man hours, or 3.81 clock hours. The question faced is the distance the crew can travel in one-half this time. This is worked out with the formula presented in Appendix B.

decreased as the number of men in the loading crew increased. (See Appendix D). For example, the five-man crew will load a 190 crate truck in 2.39 hours, while a six-man crew takes only 1.86 hours. Multiplying the crew labor time per load by the number of loads in the complement yields the total hours for loading.

(3) Any crew-load complement must take less than 10 hours for the round trip travel of the loading crew and for loading the number of loads specified — this is the work day. The six man — two load complement has a 7.22 hour work day, the five man — two load complement has an 8.28 hour work day, and four man — two load complement has a 10.3 hour work day. This last complement must be rejected as impossible within the 10 hour day restriction — that is, not feasible.

(4) The total quantity of labor time needed for each element of the matrix in Figure 4 is determined. This includes travel time for foreman, pickup labor, and truck drivers, as well as time spent loading birds. Total labor time consists of two elements: (a) the work day multiplied by the crew size specified and (b) the travel time for the truck drivers. Truck driver time enters these calculations in two ways: One driver is always with the crew so the travel time for one truck driver and all driver loading time is included when the length of work day is multiplied by the crew size. Travel time for all additional drivers is added to get total man hours for loading and travel.

The crew-load complements using the least amount of labor to assemble the poultry are chosen from among those that are feasible. The first step in this process is to determine the least labor use complement in each column. In this case (Supply Band III), for those complements which pick up only one load with one crew of men, the complement which uses the least amount of labor time contains four men. For those complements which pick up two loads with one crew of men, the complement which uses the least amount of labor time contains five men, and so on for the other columns. This same process of developing total labor time and seeking the minimum labor use complement by columns was repeated for the part load of 20 crates.

Sets of crew-load complements sufficient to assemble the poultry located in the band were then established. Assembly of these loads can be accomplished with a number of different sets of complements as shown in Table 3. Set B for instance is made up of two complements of five men and two loads each plus one complement of four men and 1.05 loads.

Total man hours for each of these sets of complements are shown in Table 3. Sets A and B take 149.4 and 121.6 hours respectively. Sets C, D, E, F, and G all take about 110 hours. However, Set H made up of one complement of 9 men and 5.05 loads uses only 102.2 hours, and was chosen as the least-cost Set.

2. Travel and Loading Time

Total labor use by crews of different sizes is a function of travel time (which increases as the crew gets larger) and loading time (which decreases as the crew gets larger). The former remains fixed per man regardless of the size of the crew.

Table 3. Sets of Complements of Men and Loads Which Will Assemble Poultry From Band III with 190 Crate Trucks, and Man Hours Required for Each Set.

Set	Make Up of Complements		Number		Total
	Men	Loads	Complements	Men	Man Hours*
A	4	1	5	20	138.0
	3	.05	1	3	11.4
			6	23	149.4
B	5	2	2	10	89.8
	4	1.05	1	4	31.8
			3	14	121.6
C	6	3	1	6	61.5
	5	2.05	1	5	49.0
			2	11	110.5
D	6	3.05	1	6	65.5
	5	2	1	5	44.9
			2	11	110.4
E	7	4	1	7	77.7
	4	1.05	1	4	31.8
			2	11	109.5
F	7	4.05	1	7	81.9
	4	1	1	4	27.6
			2	11	109.5
G	9	5	1	9	98.2
	3	.05	1	3	11.4
			2	12	109.6
H	9	5.05	1	9	102.2

* Derived from Figure 4. Cannot be calculated from data in this table.

The combined effect of these is illustrated for Band III in Figure 5. This band has a daily volume of 14,400 birds. It shows the relationship between the number of men in the crew and the man hours used in travel and in loading for the one, three, and five load complements of Figure 4. The round trip travel time is 3.5 hours. For the four man pickup crew with three men traveling together (one foreman and two pickup laborers) the man hours of travel time is 10.5 hours (3x3.5 hours). The travel time for the truck driver who assists in pickup is not included since he must make the trip regardless. With a five man pickup crew travel time is 14 man hours (4x3.5 hours) and with a six man pickup crew it is 17.5 man hours (5x3.5 hours). Larger crews use more man hours in travel time.

However, labor productivity rises as crew size increases, so larger crews use less loading time for any given volume of poultry. For the four-man crew (one foreman, two pickup laborers, one truck driver) loading time for a 190 crate truck is 3.4 crew hours or 13.6 man hours. For the five-man crew loading time is 2.39 crew hours or 11.95 man hours, and for the six-man crew loading time is 1.86 crew hours or 11.16 man hours.

Because average productivity increases with crew size up to nine men and then starts to decrease, it would be expected that optimum crew size would never be less than nine men. Using less than nine men would be irrational whatever the cost of labor and the value of the pickup service. However, crew travel must also be considered in addition to loading.

Combining both travel time and loading time shows the total use of time by the crew (excluding truck travel time). For complements involving one load the total man hours required for labor and foreman travel and for loading is 24.7 for a three-man crew, 24.1 for a four-man crew, and 26.0 for a five-man crew. The four-man crew uses the least amount of time. As crew size increases beyond four men the man hours of travel time increase faster than the man hours of loading time decrease.

As the number of loads per complement increases the crew size at which total man hours is least gets larger. For one load complements the minimum man hours for loading and travel (excluding driver travel) is at a crew size of four; for three load complements it is at a crew size of five, and for five load complements it is six, for this density and distance situation. The travel time has less influence as the number of loads in a complement increases. However, the restriction of a ten hour day must also be considered in selecting the crew size in each column. The effect of this restriction is to force the crew size for the complements with the larger number of loads to much higher crew numbers then is optimum, as indicated in Figure 5.

3. *Assembly Timing*

For the set of crew-load complements tentatively established, it is necessary to set up a time schedule for four purposes: 1) to establish truck size, 2) to determine which if any of the trucks can make more than one trip, 3) to make sure the unloading of the trucks can be accomplished within a nine hour period at the plant, and 4) to determine if adjustment in crew size can result in fewer trucks without violating the restriction of a 10 hour day. Such a schedule is shown in Table 4 for Supply Band III, 5,000 pound density level, 190 crate trucks. Other bands will have similar schedules for each truck size and density level.

The poultry in Supply Band III will be assembled with one complement of 5.05 loads and nine men. However, it may be possible to use less than six trucks. Reference to Appendix C, Figure C-2 shows that at the 5,000 pound density level the impound point for Supply Band III cannot be serviced twice a day by a 190 crate truck. But since the last load is only .05 load, its loading time is so short that it is possible for Truck No. 1 to return for this second small load. This is indicated in the schedule in Table 4.

The receiving time at the plant can be determined from the schedule by subtracting the "time" at which the first load arrives at the plant from the time at which the last load is unloaded. In Table 4 this is the time elapsing between 4.67 hours and 10.25 hours or 5.58 hours, well within the nine hour plant receiving time restriction.

Table 4. Schedule of Times Involved in the Assembly of Supply Band III, 190 Crate Trucks, 5,000 Pound Per Year Density Level, 9 Man-6 Load Complement

Activity or Location	Load Number 1	2	3	4	5	6
Truck Number	1	2	3	4	5	1
			(hours)			
Leave Plant*	0	1.17	2.34	3.51	4.68	5.85
Travel Time†	1.75	1.75	1.75	1.75	1.75	1.75
Arrive*	1.75	2.92	4.09	5.26	6.43	7.60
Load Time†	1.17	1.17	1.17	1.17	1.17	.06
Leave Farm*	2.92	4.09	5.26	6.43	7.60	7.66
Travel Time†	1.75	1.75	1.75	1.75	1.75	1.75
Arrive Plant*	4.67	5.84	7.01	8.18	9.35	9.41
						.80‡
Unload Time†	.86	.86	.86	.86	.86	.04
Unloaded*	5.53	6.70	7.87	9.04	10.21	10.25
Waiting Time†	.32§					
Leave Plant*	5.85					

* Clock time.

† Elapsed time.

‡ Load 6 waits at processing plant for .80 hours while load 5 is being unloaded.

§ Truck 1 waits at plant .32 hours before starting trip back to farm to pick up load 6.

IV. Cost of Broiler Assembly

The physical input-output relationships or technical coefficients in broiler assembly have been developed and the physical input quantities required for each firm at each density situation determined. Appropriate cost rates must be applied to the physical input quantities to establish a function relating output and cost. The cost rates developed and used in this study are those appropriate for current New England conditions.

Labor and Management Costs

Pickup labor. truck drivers. and crew foremen receive hourly wages of $1.26. $1.58. and $2.27. These wages include five percent fringe benefits and are typical for the industry.

Firm A presents some difficulties in deciding on labor payments. For instance, at the 5,000 pound per square mile per year density level. the foreman and pickup labor work 4.38 hours on assembly. This is less than half of a full day and requires some consideration of the rest of the day. It is assumed that other alternative employments are available in the poultry industry for the rest of the day. For instance, after assembly is completed the crew can go into the processing plant and work an additional four to six hours on eviscerating, packing, or maintenance. With most other sizes of firms and densities the crew works more than nine hours on assembly.

The labor cost for each size of assembly firm at the 5,000 pound density level is shown in Table 5. The cost for pickup labor and crew foremen is the sum of the time spent by the crew traveling from plant to farm, loading trucks, and returning to the plant, multiplied by the appropriate wage rate. For truck drivers the cost is the amount of time spent traveling to the farm, helping to load, and returning to the plant, multiplied by the driver wage rate. Driver time starts when he steps into the truck to begin the trip to the farm and ends when he gets back to the plant and parks. If the truck takes more than one trip, the driver time includes the time at the plant necessary to unload and reload the truck, that is, the turn around time. The driver does not service the truck. The cost to the assembly firm of servicing is included elsewhere as part of repairs and maintenance. Unloading and loading crates and shifting truck's position is done by the receiving crew at the plant and the cost of these is covered by the processing plant.

Table 5. Labor Use and Cost for Six Model Assembly Firms at the 5,000 Pounds Per Square Mile Per Year Density Level

Firm	Loader	Foreman	Driver	Total
		(hours per day)		
A	17.52	4.38	5.64	27.54
B	55.74	9.29	23.05	88.54
C	121.61	18.70	51.14	191.45
D	177.11	27.95	72.57	277.63
E	289.84	46.72	119.78	456.34
F	414.41	65.92	165.48	645.81
		(dollars per day)		
A	22.08	9.94	8.91	40.93
B	70.23	21.09	36.42	127.74
C	153.22	42.45	80.80	276.47
D	223.16	63.45	114.56	401.27
E	365.20	106.05	189.25	660.50
F	522.16	149.64	261.46	933.26

The management function in the assembly firm involves primarily the development of schedules for crews and trucks within a system established by the entrepreneur. The manager also makes the decisions on the repair, maintenance, and purchase of trucks and crates, hires and fires labor, and maintains accounting systems. It is assumed that managers are hired from the manager market on a yearly wage basis but that only a partial amount of this wage is assigned to the assembly function. A standard salary of $6,000 is paid all managers. The partial allocations of managers' wages to the assembly firms are: Firm A – 1/10, Firm B – 1/4, Firm C – 3/8, Firm D – 1/2, Firm E – 3/4, and Firm F – 1. The remainder of the managers' time and wages is considered to be carried by the processing firms.

In addition to managers' salaries the management function includes office rent and office help. These are $959 for Firm A, $2,022 for Firm B, $3,215 for Firm C, $4,313 for Firm D, $5,598 for Firm E, and $6,909 for Firm F.

Cost of Weight Loss

Weight loss of birds during assembly is a function of time in crates. The cost of this weight loss can be quantified for an assembly firm buying birds from growers and selling them to processors on a weight basis. For example, if the assembler buys broilers for 16 cents per pound and sustains a three percent weight loss, this represents a loss of one-half cent per pound. In an integrated operation the cost of this weight loss will show up only when the eviscerated bird is sold.

However, it is necessary to develop some measure of economic cost of weight loss in live hauling and relate this cost to the assembly enterprise. This cost is required so that the economic differences between levels of production density for a given size of assembly firm, or between sizes of assembly firms for a given level of production density can be determined.

Pricing live broilers is difficult because few markets exist for live birds, especially in the highly commercialized areas of New England. The prices reported monthly by the University of Connecticut are considered to be representative of New England. The average price for the 12 month period ending with May, 1963 was 16 cents per pound, and this price is used in establishing the cost of weight loss in transit.[1]

Crate Costs

Crates are an essential input of the assembly function. The number of crates owned by each firm is equivalent to its truck crate capacity plus additional crates equivalent to 20 percent of the firm's daily volume. Firm C, for example, has a daily volume of 100,800 pounds or 28,800 birds, which is equivalent to 1,920 crates of birds. If this firm owns eleven 190-crate trucks (each taking one trip a day) its truck crate capacity is 2,090 crates; if it owns six 190-crate trucks (all but one making two trips a day) its truck crate capacity is 1,140 crates. In either

---

[1] *Poultry Marketing*, Extension Service, College of Agriculture, University of Connecticut, Monthly, July, 1962 to June, 1963.

case the firm will own an additional 384 crates. These extra crates, equivalent to 20 percent of daily firm volume, permit some crates to be in a repair status, and if necessary provide sufficient crates so that empty crates can be waiting for reloading.

Both fixed and variable costs are associated with the ownership of crates. Fixed costs include interest at three percent, taxes at one percent, insurance at one percent, and time depreciation at 20 percent of new investment cost of $3 per crate. Variable costs include wear depreciation and repairs. Both of these variable costs bear a relationship to use of the crates. The type of crate used in New England has a life of about 750 trips as determined from the survey of operating firms. Repairs include only replacing broken rounds and repairing doors. The annual rates for repairs and time and wear depreciation are shown in Figure 6.

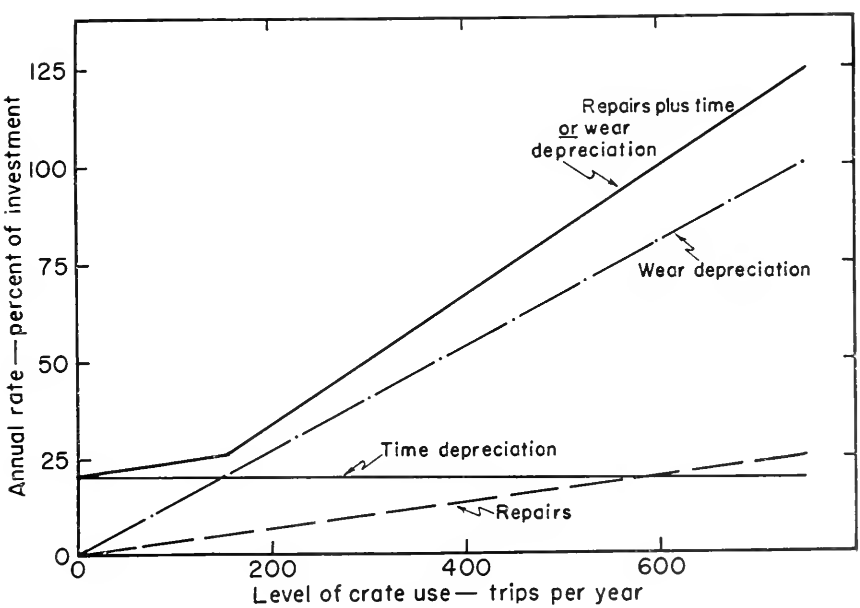
Average number of trips per year for the crates for each firm was developed by dividing the number of crates owned into the daily truck crate capacity of the firm and multiplying by 247 days. This was applied to the line in Figure 6 labeled "Repairs plus time or wear depreciation" to determine annual rate for repairs and depreciation for a new $3 crate.

Automobile and Truck Costs

Costs incurred by assembly firms to operate automobiles in which crews are transported was set at seven cents per mile per crew. Therefore, a suitable automobile owned by a member of the crew is specified.

Some truck costs are associated with ownership and others with use. However, truck costs do not break neatly into the two classical divisions

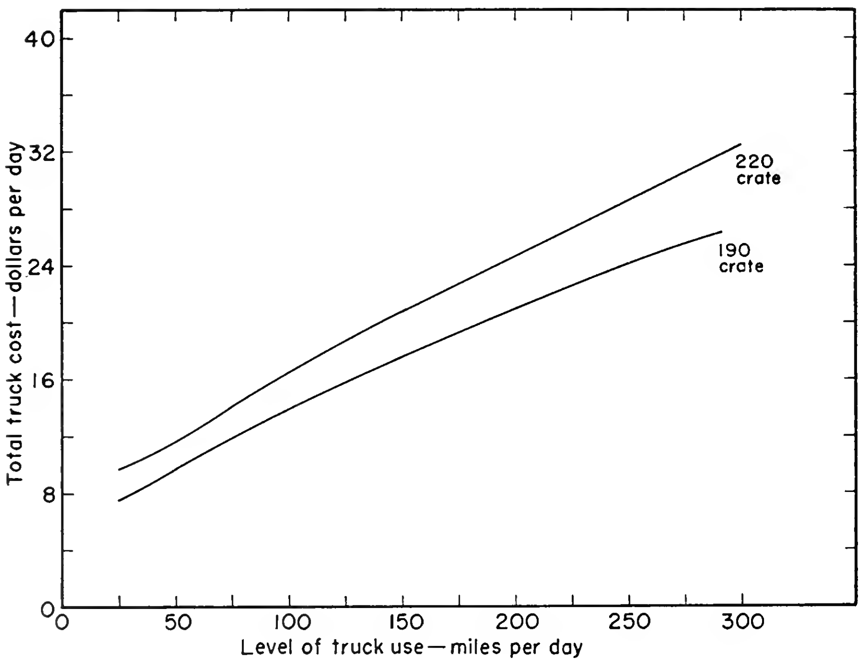
Figure 6. Relationship of Annual Rates of Repairs and Depreciation for Crates to Crate Trip Per Year.



of fixed and variable costs. Fixed costs are associated with ownership and do not vary because of use. They include antifreeze. license, registration, and insurance. Variable costs have a definite and fairly constant relationship to miles traveled and include gas, tires, oil, and lubrication. Finally, some costs are both fixed and variable in nature including maintenance and repairs, depreciation, interest, and property taxes.

The method of determining each of these costs is shown in Appendix B. For each type of truck the cost at each daily mileage level was determined. The costs were then summed to develop a curve showing total daily costs per truck at each daily mileage level. This is shown in Figure 7 for the two truck sizes. The daily mileage traveled by each truck of each firm was applied against these curves to develop the total daily truck costs for each firm.

Figure 7. Cost of Truck Operation at Various Levels of Use.



Total Costs of Assembly

For any given density level assembly cost per pound rises as size of assembly firm increases. Table 6 shows the per pound costs of assembly for each of the six model firms at the three density levels.

Table 6. Costs of Broiler Assembly (cents per pound) for Six Firm Sizes at Three Density Levels.

	Firm and Annual Volume (million pounds)					
	A (4.15)	B (12.45)	C (24.90)	D (34.58)	E (51.87)	F (69.16)
	1,000 Pound Density Level*					
Truck	.147	.177	.230	.249		
Labor	.328	.335	.405	.481		
Crate	.014	.012	.012	.012		
Car	.028	.028	.043	.057		
Management	.038	.028	.022	.021		
Shrinkage	.326	.375	.417	.435		
Total	.881	.955	1.129	1.255		
	5,000 Pound Density Level					
Truck	.099	.104	.133	.151	.163	.183
Labor	.244	.253	.274	.287	.315	.333
Crate	.014	.013	0.12	.012	.012	.012
Car	.012	.008	.010	.013	.018	.022
Management	.038	.028	.022	.021	.019	.019
Shrinkage	.230	.241	.276	.299	.327	.350
Total	.637	.647	.727	.783	.854	.919
	25,000 Pound Density Level					
Truck	.084	.063	.072	.075	.085	.098
Labor	.200	.205	.216	.217	.229	.240
Crate	.011	.010	.011	.011	.012	.013
Car	.005	.003	.004	.004	.007	.009
Management	.038	.028	.022	.021	.019	.019
Shrinkage	.179	.228	.218	.229	.248	.275
Total	.517	.537	.543	.557	.600	.654

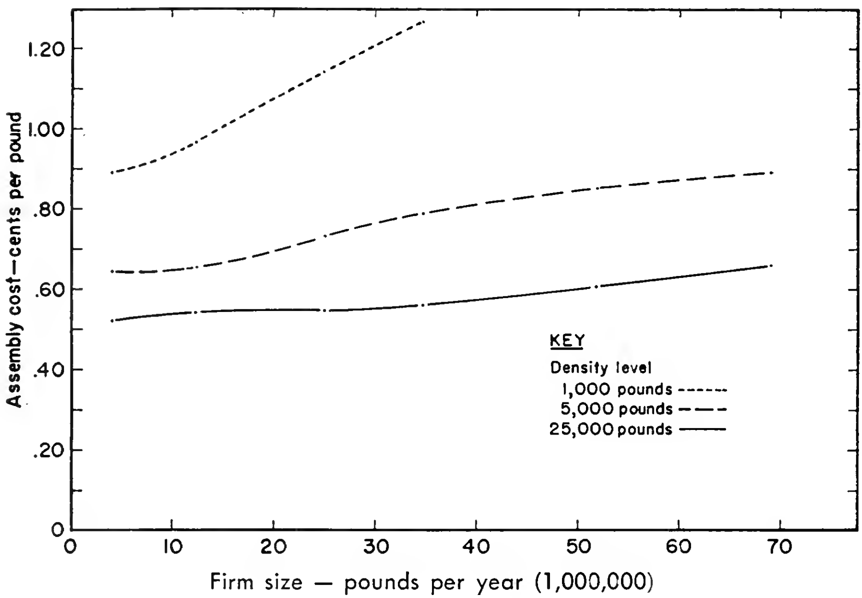
* Because of the 10-hour restriction on truck driver, pickup labor, and foremen work day, Bands V and VI cannot be reached at the 1,000 pound density level, so Firms E and F cannot exist.

The cost per pound for assembly at the low density level of 1,000 pounds per square mile per year rises steeply as firm size increases.[2] The cost per pound for assembly at the 5,000 pound density level rises less steeply. Cost increases from 0.637 cents to 0.919 cents per pound, an increase of 0.282 cents or about 44 percent with an increase in size of firm from 4.15 million pounds to 69.16 million pounds annually. With the same change in size of firm the cost of assembly at the 25,000 pound per square mile per year density level increases only by 0.137 cents per pound or 27 percent.

[2] Within the restrictions of this study no assembly firm can have a size greater than about 45 million pounds per year at the 1,000 pound density level. This is due to the physical impossibility of covering distances required to assemble poultry for a plant of larger size. In this study Firm D (34.58 million pounds per year) was the largest one at the 1,000 pound per square mile per year density level.

The curves in Figure 8 show the relationship between firm size and assembly cost per pound and indicate that assembly costs tend to increase at a decreasing rate as size of firm increases. The 25,000 and 5,000 pound density cost curves rise slowly at first because at the lower volumes costs can be kept down as size of firm increases. This is due to using one crew in more than one band, so crew and foreman travel time is reduced below what it would be if separate crews had to go to each band. Such combining of bands also requires proportionately less foreman time and reduces the overhead truck costs because fewer trucks are needed.

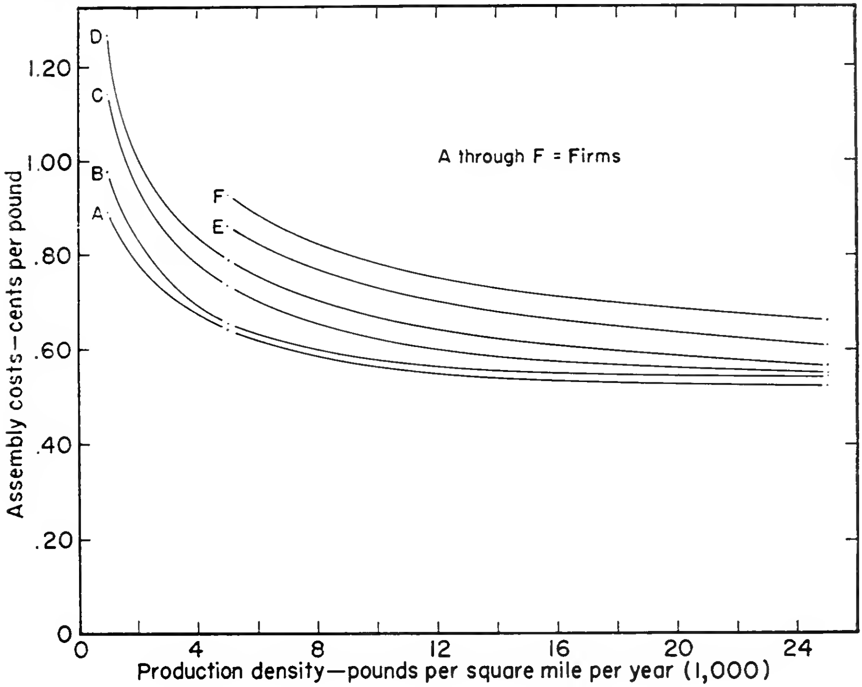
Figure 8. Broiler Assembly Cost for Firms of Various Sizes.



The effect of production density on assembly costs for each of the six firms is estimated in Figure 9 from the cost points developed in this study at the three density levels. It is evident from these curves that increasing density will have the greater absolute and percentage effects on the cost of assembly of the large firms. In moving from a density of 5,000 pounds per square mile per year to 25,000 pounds, the cost of assembly for Firm A falls 0.12 cents or 19 percent, while for Firm F it falls 0.265 cents or 29 percent.

Hauling distance, as expected, has a positive effect on assembly costs. This is shown in Figure 10, in which the assembly cost per pound is plotted against the distance from each impound point under each density situation. At each density level, the costs of assembly increase as the distance to the impound points increases. Taking each density situation separately in Figure 10, it appears that the costs rise at increasing

Figure 9. Broiler Assembly Costs at Various Production Density Levels.



rates over their lower mileage levels and then rise at decreasing rates. This behavior of the cost-mileage relationship as distance increases means that the marginal or additional cost of going one more mile initially increases and then decreases.

Application of linear regression to the cost-distance data for all three density situations combined results in the following equation:

$$A = 0.511 + 0.00809\ M$$

A = assembly cost in cents per pound

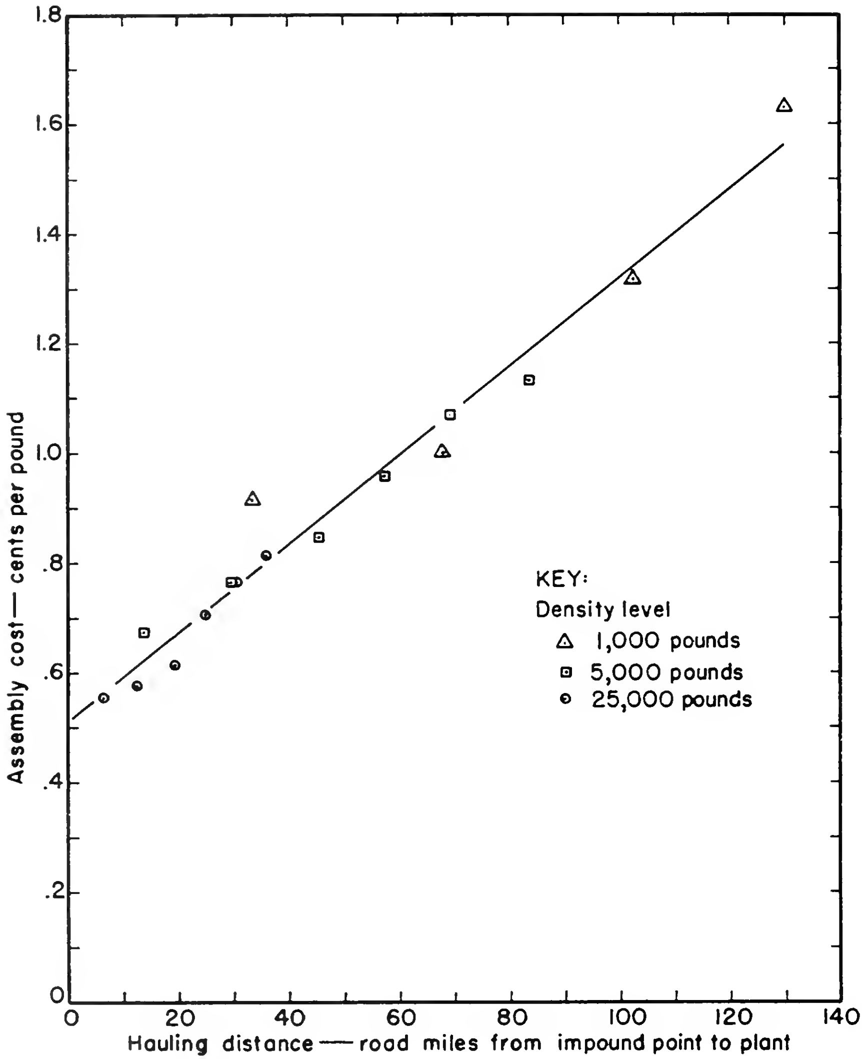
M = road miles between plant and impound point

This means that for every pound of live broiler hauled there is an initial cost of one-half cent plus about eight-thousandths of a cent for each additional mile hauled. This latter is the marginal cost per mile for each pound hauled. The coefficient of correlation is 0.984, meaning the straight line fits the points almost exactly.

This equation can be quite valuable to a hauling firm in determining the cost of moving poultry over certain distances, regardless of the production density situation. Assume an assembler has the opportunity to shift from one producer located 60 miles from the plant to one located only 40 miles from the plant and that one 220 crate truck load of birds is involved (11,550 pounds). The 60 mile trip costs him:

$$\text{Cost} = (11.550 \times .511c) + (11.550 \times .00809c \times 60)$$
$$= \$59.02 + \$56.06 = \$115.08$$

Figure 10. Broiler Assembly Costs for Various Hauling Distances at Three Density Levels, 220 Crate Trucks.



The 40 mile trip costs him:

$$\text{Cost} = (11.550 \times .511c) + (11.550 \times .00809c \times 40)$$
$$= \$59.02 + \$37.38 = \$96.40$$

a saving of \$18.68 or 93c per mile. This is the saving on one truck load, so assuming 20,000 bird farms (6.06 truck loads) are involved and each will produce five batches a year the annual saving is:

$$\text{Saving} = 6.06 \times 5 \times \$18.68 = \$566$$

V. Conclusions and Applications of Results

Combined Costs of Assembly and Processing

The long-run average cost of broiler processing falls from 3.803 cents per pound at an output of 4.15 million pounds per year to 2.642 cents per pound at an output of 69.16 million pounds per year.[1] The cost of broiler assembly on the other hand increases at the 5.000 pound per square mile per year density level from 0.637 cents per pound for the 4.15 million pound per year firm to 0.919 cents per pound for the 69.16 million pound per year firm.

By combining these costs of processing and assembly, information is obtained which is more complete and useful than either taken separately. Table 7 and Figure 11 illustrate this for the three density levels. At the very low broiler production density level of 1,000 pounds per square mile per year assembly costs rise rapidly and eventually outweigh the fall in the processing plant economies of scale. With this density level the combined assembly and processing costs reach a minimum at 4.098 cents per pound for Firm C with an annual volume of 24.9 million pounds.

In a broiler supply area with a 5.000 pound density level the minimum combined long-run average cost of processing and assembly occurs at a larger firm size than for the lower density level considered. Inspection of Table 7 and Figure 11 indicates that minimum combined costs will occur slightly beyond the 70 million pound per year firm size.

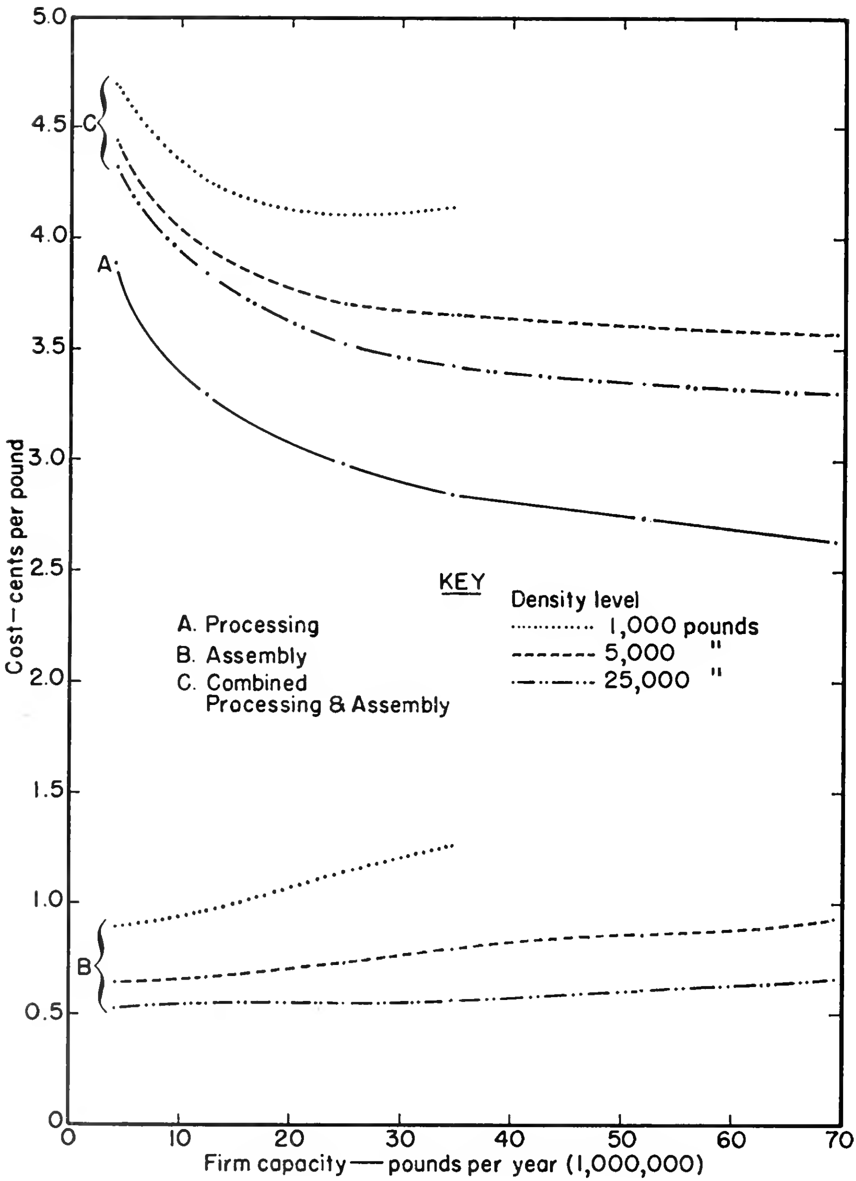
Table 7. Long-run Average Costs of Broiler Processing and Assembly for Six Firm Sizes at Three Density Levels.

Firm	Annual Volume	Processing Cost	Assembly Cost Density Level			Combined Cost Density Level		
			1,000	5,000	25,000	1,000	5,000	25,000
	(million pounds)	(cents per pound)	(cents per pound)			(cents per pound)		
A	4.15	3.803	.881	.637	.517	4.684	4.440	4.320
B	12.45	3.296	.955	.647	.537	4.251	3.943	3.833
C	24.90	2.969	1.129	.727	.543	4.098	3.696	3.512
D	34.58	2.859	1.255	.783	.557	4.114	3.642	3.416
E	51.87	2.742		.854	.600		3.596	3.342
F	69.16	2.642		.919	.654		3.561	3.296

The most dense production situation, 25,000 pounds per square mile per year, has a combined assembly and processing cost of 3.296 cents at the extreme end of the curve in this analysis — 69 million pounds per year. The analysis shows that the combined long-run average cost curve is still falling.

[1] Rogers and Bardwell, *op. cit.*, p. 16.

Figure 11. Long-run Average Cost Curves for Broiler Processing and for Broiler Assembly at Three Density Levels.



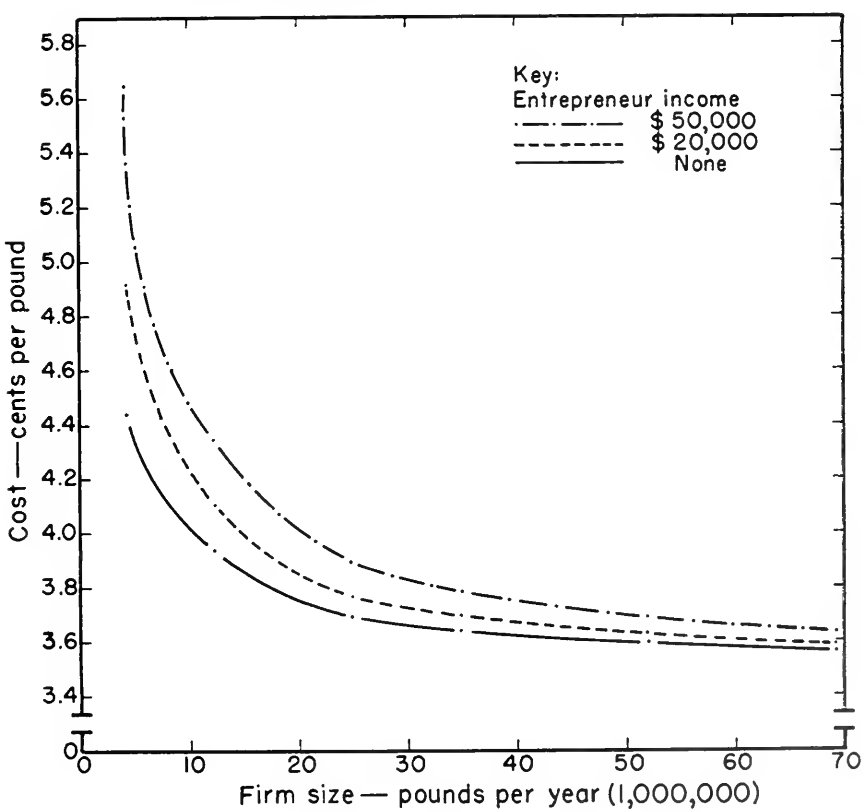
Entrepreneurial Costs

This analysis assumes an entrepreneur for all firm sizes; but costs in Table 7 do not include any payments to the entrepreneur. However, that level of income that an entrepreneur expects to receive for setting

up and operating a firm must be included as a part of the cost of production. This quantity of income will bear a close relation to the income he can receive in alternative pursuits. Thus, the entrepreneurial income is an opportunity cost to the firm.

The entrepreneur in his planning activities must determine how costs of each of the alternative firm sizes compare with those of other sizes in providing him with his required income. To indicate the effect of entrepreneurial income on the long-run costs of broiler assembly and processing, two entrepreneurial income levels, $20,000 and $50,000 per year, were arbitrarily selected and costs determined as shown in Table 8. In Figure 12 the change in the level and slope of the long-run cost curve at the 5,000 pound density level is shown for these two levels of entrepreneurial income. The entrepreneurial income is handled here as an addition to all other costs of the firm, and adds a fixed cost item to the long-run average cost curve. Treating entrepreneurial income as a constant, independent of all other anticipated costs along the planning curve, makes the planning curve more useful.

Figure 12. Effects of Several Levels of Entrepreneurial Income Payments on the Long-run Average Combined Costs of Broiler Assembly and Processing, 5,000 Pound Density Level.



Planning

The long-run average costs of assembly and processing combined is more vital information to entrepreneurs than the costs of conducting either of these marketing services separately. It is quite evident that economies of scale do exist in processing, and that these economies are not exhausted with current technology even at the 70 million pound per year processing plant size. However, the results further indicate that the entrepreneur must consider density of production and its effect on assembly cost before deciding on the firm size with the least combined cost.

In an area producing only 1,000 pounds of broilers per square mile per year the entrepreneur should consider that least cost, not including his own income, is achieved with combined facilities at a capacity of about 25 million pounds per year. Additional volume for this entrepreneur with no increase in density might well come from a set of duplicate assembly and processing facilities at some location where they are not in competition with the first set of facilities. However, the level of entrepreneurial income demanded will also influence optimum firm size. An entrepreneur demanding $20,000 annual income will find that at this low density level the optimum sized operation for him is at about 35 million pounds. (See Table 8). This is further illustrated in Figure 12 for the 5,000 pound density level. As entrepreneurial income increases the slope of the curve at any firm size is steeper.

Production density as used in this study refers to the density faced by an individual firm, not the density of the whole area from which that firm obtains its supply. However, the broiler industry is highly dynamic

Table 8. Average Cost of Entrepreneur at Each Plant Size Assuming $20,000 and $50,000 Annual Entrepreneurial Payment and Long-Run Average Costs of Processing, Assembly, and Entrepreneur Combined.

	Firm Capacity — Pounds Per Year (million)					
Entrepreneur Income Level	4.15 A	12.45 B	24.90 C	34.58 D	51.87 E	69.16 F
	(cents per pound)					
$20,000 Per Year						
Entrepreneurial Cost	.482	.161	.080	.058	.039	.029
All Costs at Three Density Levels						
1,000 Pounds Per Year	5.166	4.412	4.178	4.172	. . .	. . .
5,000 Pounds Per Year	4.922	4.104	3.776	3.700	3.635	3.590
25,000 Pounds Per Year	4.802	3.994	3.592	3.474	3.381	3.325
$50,000 Per Year						
Entrepreneurial Cost	1.205	.402	.201	.145	.096	.072
All Costs at Three Density Levels						
1,000 Pounds Per Year	5.889	4.653	4.299	4.259	. . .	. . .
5,000 Pounds Per Year	5.645	4.345	3.897	3.787	3.692	3.633
25,000 Pounds Per Year	5.525	4.235	3.713	3.561	3.438	3.368

as noted in a previous study.[2] Many shifts are taking place in the location of broiler production, in the size of firms in production and marketing, in the technology of growing and marketing, and in the structure of the broiler industry. This means that planners cannot assume a static condition in the industry.

In most cases any steps taken by a marketing firm to increase its supply will be expensive; expanding the supply area raises average assembly cost because of increased hauling distance, and increasing the density of production of a given supply area requires payments to potential producers above the current level to induce them to produce for the firm. The results of this study should be very useful to an entrepreneur in determining his optimum economic position in terms of size of firm for providing the two marketing services, and what he can afford to pay for density to reach his optimum income position.

[2] G. B. Rogers, W. F. Henry, A. B. Brown, and E. T. Bardwell, *Marketing New England Poultry, 1. Characteristics of the Processing Industry*, University of New Hampshire, Agricultural Experiment Station Bulletin, No. 444, September, 1957.

APPENDIX A

Location of Impound Points and Relationship of Radial Distance to Road Distance

Location of Impound Points

The impound point concept is a very convenient one for a study of this type. On the average, all the poultry in a given supply band is assumed to be located at impound points on a circle which is a certain distance inside that band. The research problem is to determine, under all conditions of density and distances, the location of this circle on which the impound points are located. Since the broilers are located evenly over the surface of the supply band, the problem is to locate a circle within the supply band which divides the area of the band (and the quantity of poultry) in half. This is found by the following equation:

$$P = \sqrt{\frac{Q^2 + N^2}{2}}$$

Where:

P = radial distance in miles from the processing plant at the center to the circle of impound points

N = radial distance in miles from the processing plant at the center to the inner rim of the supply band

Q = radial distance in miles from the processing plant at the center to the outer rim of the supply band

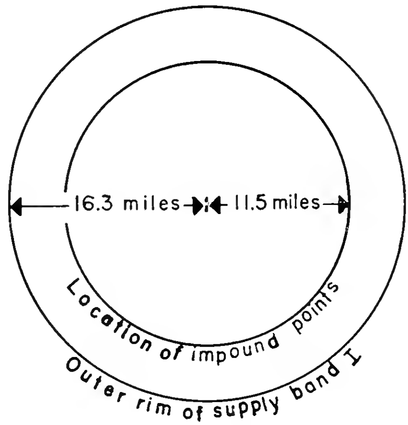
One use of this equation must be made for Supply Band I because for that supply band the inner rim and the processing plant coincide at a point, so N has a value of zero. Such a situation is shown in Figure A-1 for Supply Band I, 5,000 pound per year density level. Solving by the above equation results in the impound points being located on a circle 11.5 radial miles from the processing plant at the center:

$$P = \sqrt{\frac{16.3^2 + 0^2}{2}} = 11.5$$

The other use of this equation is for all other supply bands. For these the inner rims are some distance from the center. Figure A-2 illustrates Supply Band II at the 5,000 pound density level where Q is 28.2 miles and N is 16.3 miles from the processing plant at the center. Solving by the above equation results in the impound points being located on a circle 23 radial miles from the processing plant at the center.

For a supply band where the inner rim and the processing plant coincide at a point (Supply Band I) the impound points will always be on a circle with a radial distance equal to 70.71 percent of the radius of the band. This is the maximum distance that impound points can be from the center of a circle or inner perimeter of a band. For supply bands whose inner rims are some distance from the processing plant at the center, the impound points will fall on a circle that ranges between 50 and 70.71 percent of the width of the band from the inner rim. This

Figure A-1. Location of Impound Points in Supply Band I, 5,000 Pound Per Square Mile Per Year Density Level.



circle approaches 50 percent of the width of the band as the width becomes smaller or the distance between the inner perimeter and the processing plant becomes longer.

Relationship of Road Distance to Radial Distance

Numerous studies have shown empirical analyses of the difference between actual road distance and radial or airline distances to the same points in a given area. Bressler and Hammerberg in a milk assembly study in Connecticut states that "Despite natural barriers and the winding road network in Connecticut, there is a high correlation between road and airline distance. An investigation of this relationship has indicated that the distances from individual farms to markets by improved roads may be represented approximately by 2.4 miles plus 102 percent of the airline distance. This regression describes the relationship very exactly, resulting in a coefficient of correlation of 0.992."[1] Henry and Seagraves in their report on broiler production in North Carolina stated "In empirical studies, air distance should be converted to road distance. In the vicinity of Robbins, North Carolina, the average road distance is $1.703 + 1.16\ A$, where A is the air distance in miles."[2]

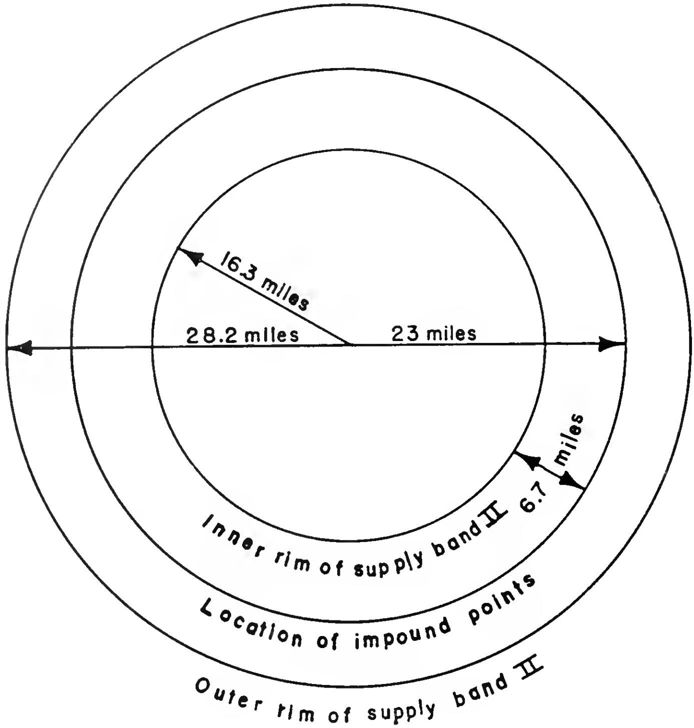
Theoretically, the road distance should have a relationship to airline or radial distance such that the road distance is the summation of the radial distance and the lateral distance to the farm. If all farms are located on radial roads from the central point, then the relationship will be 1:1. As the number of farms located off radial roads increases, the ratio becomes greater.

---

[1] R. G. Bressler and D. O. Hammerberg, *Efficiency of Milk Marketing in Connecticut, 3. Economies of the Assembly of Milk*, Storrs Agricultural Experiment Station Bulletin, No. 239, p. 44.

[2] W. R. Henry and J. A. Seagraves, "Economic Aspects of Broiler Production Density," *Journal of Farm Economics*, Vol. XLII, No. 1, p. 3.

Figure A-2. Location of Impound Points in Supply Band II.
5,000 Lb. Per Square Mile Per Year Density Level.

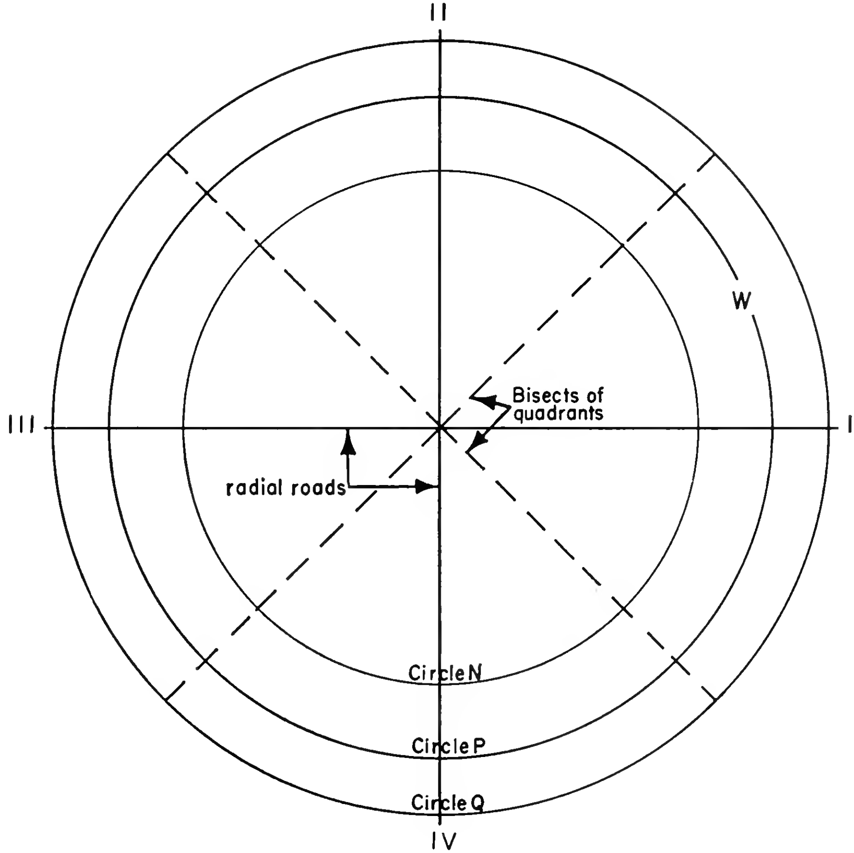


It is assumed that all poultry to be assembled is, day by day, aggregated at some impound point in each of the applicable production bands. The impound point on the average is located somewhere off the radial road, meaning that its road distance is the summation of the radial and the lateral distance.

In any of the production bands, the lateral distance from a radial road to an average location between two radial roads will diminish as the number of radial roads increases. Counting the number of roads leading from a center that follow a radius is difficult. As a first approximation the locations of processing plants are assumed to have at least four such radial roads. Using this number, the map in Figure A-3 was constructed. This is not part of the analysis of assembly costs, it is a simplified illustration. The outer rim of the supply band (Q) is 60 miles from the center and the inner rim (N) is 40 miles from the center. Using the equation developed above, the average location of flocks will be 51 miles from the plant or 11 miles inside the band. All the poultry on the average is located on the center circle (P) in Figure A-3.

For any one day's pickup it is assumed that all the poultry in the band is located at one impound point. This impound point must be somewhere on or between two radial roads from the plant. Since the pickup

Figure A-3. Hauling Routes and Average Location of Poultry Relative to Road Network.

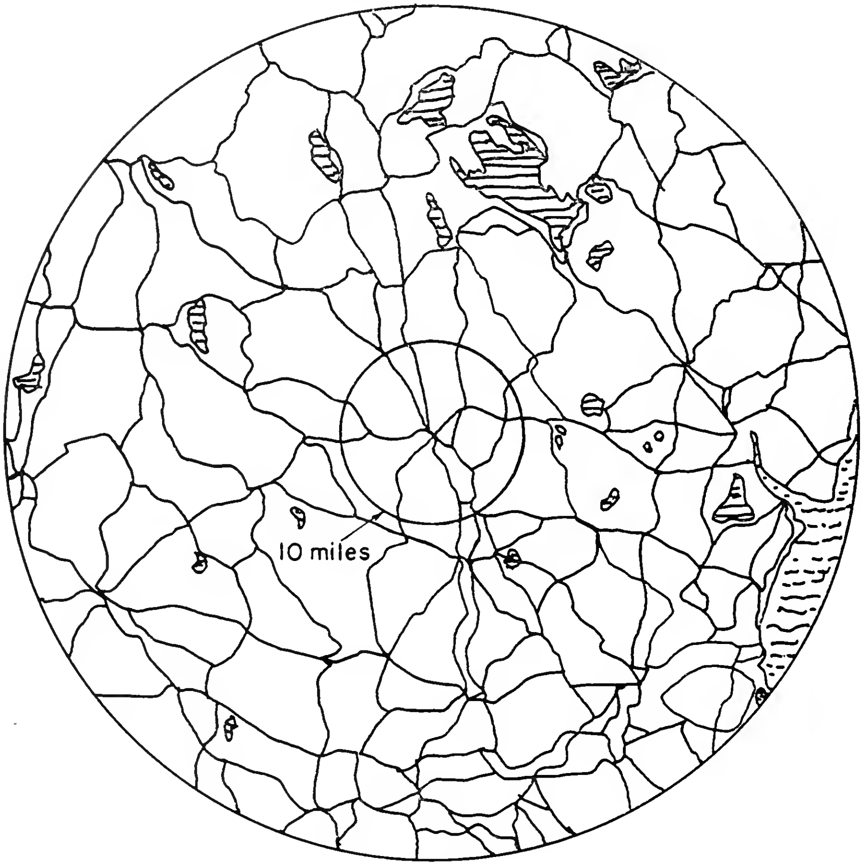


can be accomplished along either of these radial roads, this must mean that the average location of the poultry is half way between a radial road and a line which bisects the distance between two radial roads, Point W in Figure A-3.

The location of Point W in miles from the plant bears a definite relationship to the radial distance of Circle P, and the lateral distance in from Road I. The circumference of Circle P, the average pickup circle, is $2\pi r$, so the segment of this circle serviced by Road I in the northeast quadrant is one-eighth of that or $\frac{1}{4}\pi r$. However, the lateral distance into Point W is one-half of that so is equal to $\frac{1}{8}\pi r$. Adding this to the radial distance of Circle P yields $\frac{1}{8}\pi r + r$ as the distance from the plant to Point W. This yields $0.3927r+r$, or road distance to Point W is 1.3927 times radial distance.

To test this model under New Hampshire conditions an area surrounding Concord was studied (Figure A-4). On a road map of the area a sample of locations was specified and road and radial distances to Con-

Figure A-4. Road Network Surrounding Concord, New Hampshire.



50 Miles

cord were measured. A regression equation of the form D = a + b P was derived:

$$D = -1.534 + 1.351P$$

Where:

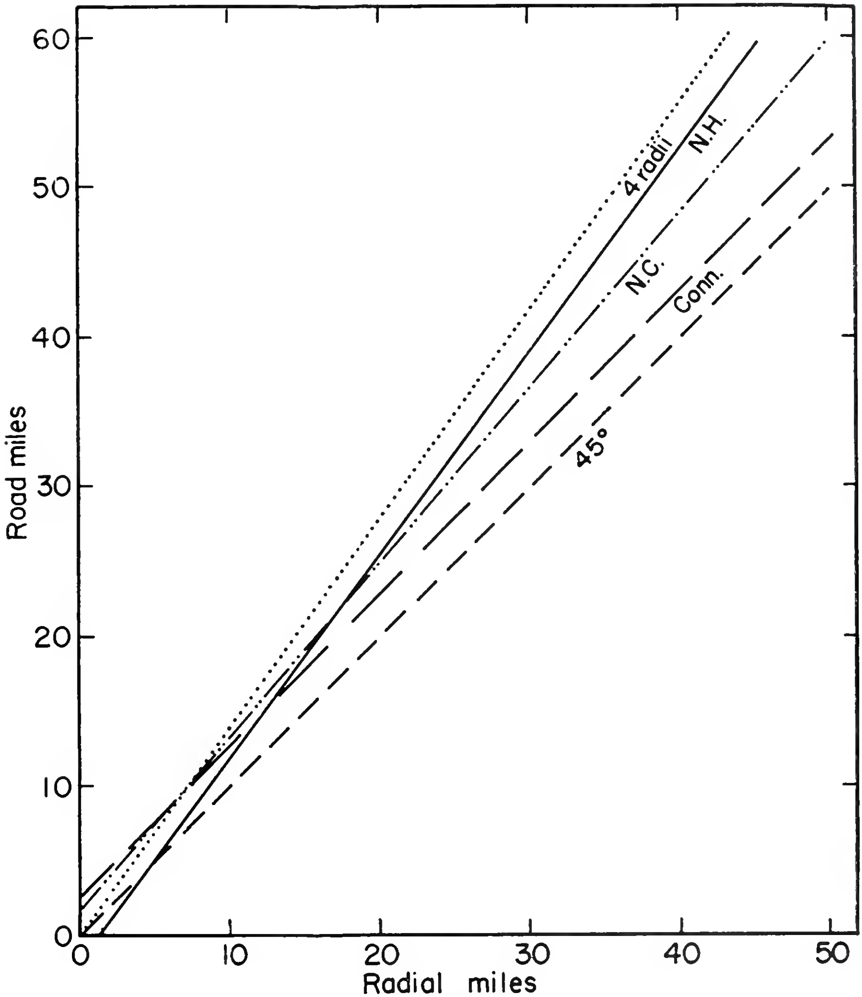
D = road distance in miles

P = radial distance in miles

(correlation coefficient: 0.982)

Figure A-5 shows the theoretical limits to the road mile – radial mile relationship. If every farm is located on a radial road, the 45-degree line will apply with the regression equation having an *a* value of zero and a *b* value of 1.0. This also means that a very large number of radial roads exists, assuming an even distribution of farms over the countryside. The 4 radii line in Figure A-5 is the second limit, resulting from the theoretical model discussed above. This line has an *a* value of zero

Figure A-5. Theoretical Relationship to Road-radius Relationship, and Results of Three Empirical Studies.



Regression values

	a		b
4 radii	0.000	+	1.3927x
N. H.	-1.534	+	1.3510x
N. C.	1.703	+	1.1600x
Conn.	2.400	+	1.0200x
45°	0.000	+	1.0000x

and a *b* value of 1.3927. In between these two limits the results of the three empirical studies are shown. The regression line developed at Connecticut has a *b* value of 1.02. Assuming that farms are distributed evenly, and that lateral roads start at roughly 90 degrees to the radial

roads, this would mean that 78 radial roads fan out from the Connecticut towns studied. The North Carolina study reported a b value of 1.16. With the same assumptions as mentioned above this means 10 radial roads fan out from processing plants in that state. Finally, the New Hampshire empirical study found a b value of 1.351. Again with the same assumptions this means nearly five radial roads from Concord, which on inspection seems about right.

The a values in the three empirical equations move the intercepts of the regression lines away from zero. A positive a value would mean that fewer radial roads are available to reach farms near the center than away from it. A negative a value means that more radial roads are available to reach farms near the center. The latter seems more realistic and is true for the New Hampshire regression.

It was decided to use the New Hampshire empirical regression for all distances greater than 10 radial miles. For distances less than 10 radial miles the inclusion of any a value other than zero does not seem correct, especially when that a value is based on observations extending out 50 miles. In addition, eight radial roads were counted within a ten mile radius of Concord rather than the five extending out 50 miles. For these reasons a theoretical regression is used but is based on eight radial roads. This would mean a b value of $\frac{\pi r}{16} + r$ or 1.19635, and an a value of zero. At 10 radial miles the New Hampshire empirical regression yields 11.976 road miles while the theoretical one, assuming eight radial roads, yields 11.964.

APPENDIX B

Travel Time

The time in travel was considered to be entirely associated with mileage. However, travel time includes the running time over the road plus allowance for driver comfort and food stops, and some breakdown time. In a study made at the New Hampshire Agricultural Experiment Station the relation between trip mileage and truck operating time was established.[1] That study reported only net running time, so it had to be adjusted to account for other time. This was done with data collected about egg hauling trucks. The basic shape of the relationship used in the Rogers and Woodworth study was retained because it "exhibits the logical behavior of increasing average miles per hour with greater route length."[2]

The function relating time to distance is:

1. For trips up to 60 miles in length
   $T = 2.865 + 2.6818D - 0.0102D^2$
2. For trips exceeding 60 miles in length
   $T = 50 + 1.299D$

Where:

T = time in minutes
D = road miles

The time used in truck and automobile travel was determined from this relationship. This assumes that the trucks, and the automobiles hauling the crew, travel at the same rate of speed under similar conditions.

A truck trip to collect poultry involves a round trip to the impound point in the supply band involved. The mileage the truck covers to get to that point is developed according to the procedures outlined in Appendix A. This one-way trip in miles was converted into time using one or the other of the functions above, and then doubled to obtain round-trip time.

The determinations of the size of the supply area, the radius of the supply area, the radial distance to the impound point, and the relationship between radial distance to the impound point and the hours of truck travel for a round-trip are illustrated for Supply Band IV at the 5.000 pound per year density level:

Firm C

Annual volume 24.9 million pounds

Size of supply area:

$$\frac{24.9 \text{ million pounds}}{5.000 \text{ pounds}} = 4.980 \text{ square miles}$$

Radius of Firm C supply area 39.81 miles

---

[1] G. B. Rogers and H. C. Woodworth, *Distributing and Handling Grain Feeds in New Hampshire, 2. Problems in Retail Distribution,* University of New Hampshire. Agricultural Experiment Station Bulletin, No. 427, 1956, pp. 36-37. The authors state: ". . . it covers only truck travel and no other time factors."

[2] *Ibid.*

Firm D

Annual volume	34.58 million pounds
Size of supply area	6,914 square miles
Radius of Firm D supply area	46.92 miles

Supply Band IV

Radius added by Band IV:

46.92 miles — 39.81 miles = 7.11 miles

Radial distance to impound point:

$$P = \sqrt{\frac{Q^2 + N^2}{2}} = \sqrt{\frac{(46.92)^2 + (39.81)^2}{2}} = 43.51 \text{ miles}$$

Road Distance and Time to Impound Point

Road distance

$D = a + bP = -1.534 + 1.351 \ (43.51) = 57.25$ miles

Time one way

$T = 2.865 + 2.6818 \ (57.25) - 0.0102 \ (57.25)^2 =$ 121.8 minutes or 2.03 hours

Time round trip = 4.06 hours

Similar information for all firm, supply band, and density conditions is shown in Appendix F, Table I.

APPENDIX C

Effect of Density on Daily Truck Trips

The less dense the production of poultry the greater the distance trucks must cover to assemble a given volume. The density of production coupled with the physical possibilities of truck performance establishes those volumes which can be assembled within a time limit and the number of trips a truck can make per day.

A first approximation to the relationship among density, volume, truck miles, and truck trips is worked out in Figures C-1, C-2, and C-3 which show the six supply bands corresponding to the six firm sizes under the three density assumptions of 1,000, 5,000 and 25,000 pounds per square mile per year. The annual volume of each firm is divided by the density level, which yields the supply area of the firm in square miles. Using the assumption of a circular supply area surrounding each plant, the radius of the supply area for each firm is determined, and the circumference of each supply area drawn on Figure C-1, C-2, or C-3. These supply areas must be visualized as a set of six superimposed concentric discs, each disc being a separate firm. The quantity of poultry in each concentric supply area thus constructed remains the same for the several density levels. But for different density levels the outer rim of each area will be located at different radial distances from the center.

Supply Band I is the supply area for Firm A. Supply Band II is formed by the additional area needed to make up the whole supply area for Firm B. To meet the area requirements of Firm C, Supply Band III is added to the supply area of Firm B. The successively larger firms, Firms D, E, and F, in turn require the addition of Supply Bands IV, V, and VI. Thus, the supply bands are the additional parts of the superimposed supply areas as firms get larger. A supply band, such as Band III, will have the same amount of poultry regardless of density level, but for less dense production situations a supply band will be farther from the center. In each supply band the impound point is located by the procedure outlined in Appendix A. Impound point locations within each band are shown in Figures C-1, C-2, and C-3.

The physical possibilities of 190-crate trucks reaching any given distance, loading, and returning to the plant within a 10-hour day are shown in Figure C on pages 49, 50 and 51. Possibilities for making one, two, or three trips to any given distance are shown. These possibilities are based in part on crew size, because average labor productivity per hour increases up to the nine-man level (See Appendix D); in part on the distance involved, because average truck speed varies with distance; and in part on truck size. Figure C shows the maximum radial distances that a 190-crate truck can reach with a three-man crew and with a ten-man crew. Other crew sizes within this range will result in distances between these two limits. Similar distances for the 220-crate truck would be shorter because of the added time required to load this larger truck.

The generalized form for the equation is as follows:

$$aL + 2aT + U(a-1) = 10$$

Where:

a = number of trips
L = loading time for one load, based on crew size and truck size
T = time available for travel one-way
U = unloading time for one load, based on truck size
10 = restriction of 10 hour day for driver
aL yields the total truck loading time
$2aT$ yields the total truck travel time
$U(a-1)$ yields the turnaround time when truck takes more than one trip

The calculation for the 190-crate truck, two trips per day, and a 10-man crew is (all times in hours):

$$2(1.06) + 2(2)T + .89 = 10$$
$$4T = 10 - 3.01$$
$$T = 1.748$$

T must then be converted into miles using the functions in Appendix B and the regression between road distance and radial distance developed in Appendix A applied (all distances in miles):

Equation from Appendix B:

$$T = 2.865 + 2.6818D - 0.0102D^2$$
$$1.748 = 2.865 + 2.6818D - 0.0102D^2$$
$$D = 45 \text{ road miles}$$

Equation from Appendix A:

$$D = -1.534 + 1.351P$$
$$P = \frac{45 + 1.534}{1.351}$$
$$P = 34.4 \text{ radial miles}$$

Figure C-3 shows that with a density level of 25,000 pounds per square mile per year most of the poultry can be collected on a three trip a day basis for the trucks, but Figure C-1 shows that at the 1,000 pound density level very little of the poultry can be collected on a three trip a day basis. Moreover, Figure C-1 shows that at the 1,000 pound density level the poultry in Supply Band VI cannot be reached at all under the restrictions in this study. Also, even though the impound point in Supply Band V can be reached at the 1,000 pound density level, the outer rim of the supply band cannot be reached, so this eliminates Supply Band V under the 1,000 pound per year density level condition.

Figure C-1. Broiler Supply Bands at the 1,000 Pound Per Year Density Level, and the Travel Limits for the 190 Crate Truck for One, Two, and Three Trips Per Day with Three Man and Ten Man Crews.

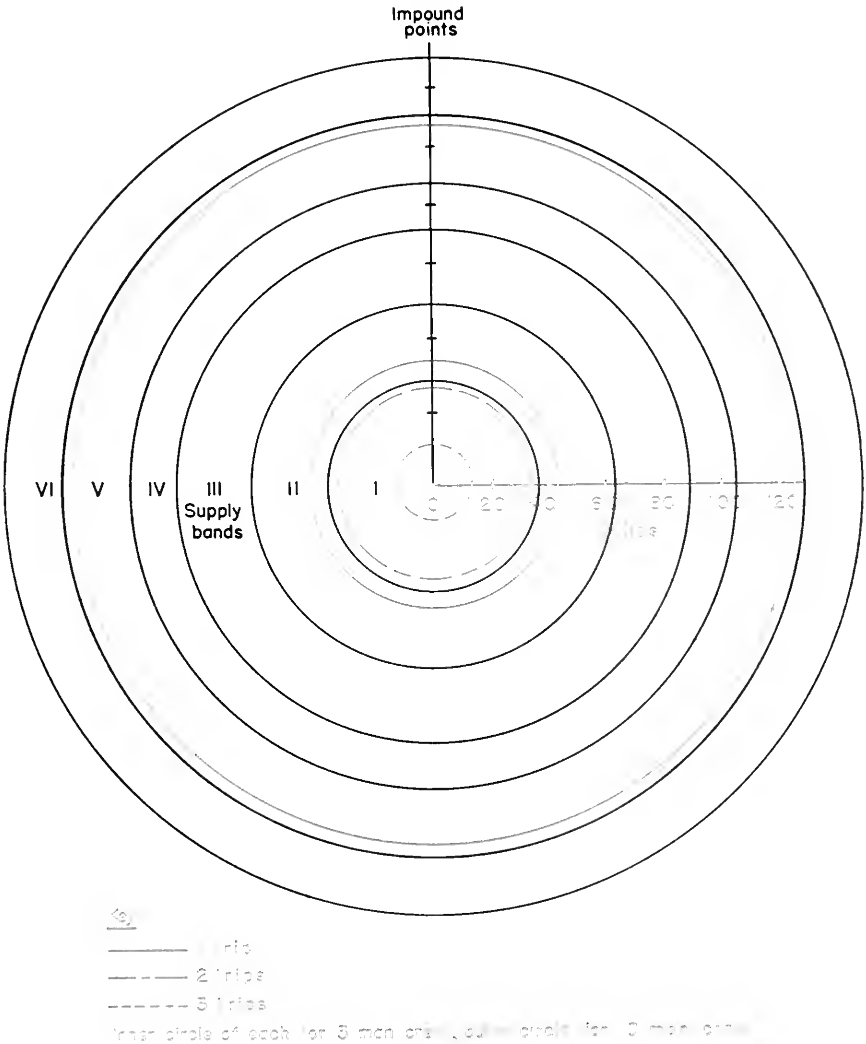


Figure C-2. Broiler Supply Bands at the 5,000 Pound Per Year Density Level, and the Travel Limits for the 190 Crate Truck for One, Two, and Three Trips Per Day with Three Man and Ten Man Crews.

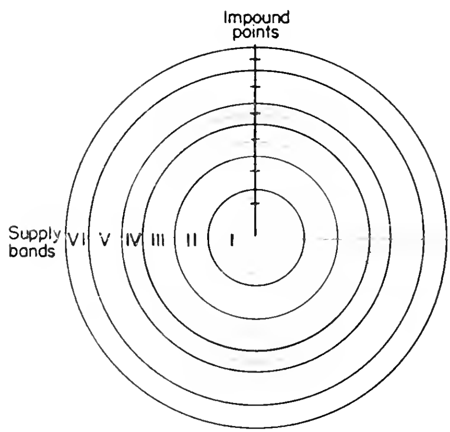
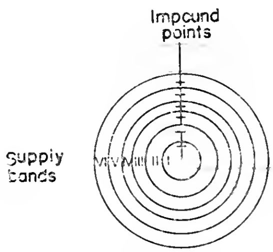


Figure C-3. Broiler Supply Bands at the 25,000 Pound Per Year Density Level, and the Travel Limits of the 190 Crate Truck for One, Two, and Three Trips Per Day with Three Man and Ten Man Crews.



APPENDIX D

Labor Productivity in Loading Live Birds

The techniques and methods used in loading live birds at farms is universally the same regardless of plant size, crew size, farm size, or geographic location. Moreover, these same techniques have been used for many years. The major activities at the farm in loading are:

1. Preparation
   a. Truck positioning
   b. Crate positioning
   c. Catching pen positioning
2. Catching and loading
   a. Driving birds into a catching pen in the poultry house
   b. Catching birds
   c. Passing birds to one or a series of men which moves the birds to the crates located on the truck
   d. Crating the birds
3. Securing load and leaving farm

For all loading operations specified in this study more than one load is required. The pickup laborers and foreman stay at the job of loading as the several trucks arrive, load, and depart. In the loading of each truck the truck driver is part of the crew. In addition to the above activities the crew must have some time for coffee breaks and the like as regular features of a work day. This time cannot be considered waste time, regardless of the quantity of poultry to be loaded. In this study, this amount of time is specified as 40 minutes per man per day on a full-day basis. Productivity coefficients include this time.

The daily time records of a New Hampshire assembler were examined and a number of trip observations were taken from them. This firm kept complete time records of all activities of all trucks and all crews with number of men in each crew. From these data the amount of time spent by the crew in picking up and loading poultry was determined, including time for personal needs, and is shown in Table D-1.

The productivity rates determined under New Hampshire conditions were compared with those in North Carolina, Connecticut, and Maine reports. Henry found that with crews of six men the over-all average time was 5.17 man-hours per 100 crates in on-truck crating.[1] He specified that "Those time requirements include all labor from the time that the crew began unfastening the empty crates on the truck to the time that the crew fastened the last stack of filled crates into place; they also include time spent in getting drinking water and going to rest rooms." Converted to output per man hour this is 860.6 pounds. This is shown in Table D-1 along with the New Hampshire data.

---

[1] *On Truck Crating Reduces Broiler Hauling Costs,* William R. Henry, North Carolina State College, Department of Agricultural Economics, A. E. Information Series No. 63, February 1958, pp. 13-15.

Table D-1. Labor Productivity in Catching and Crating Live Broilers and Loading Crates on Trucks, by Crew Size.

Crew Size*	Average Productivity Per Man Hour				Marginal Productivity Per Hour
	New Hampshire	Connecticut	Maine	North Carolina	New Hampshire
(men)		(pounds)			(pounds)
3	563				
					1,238
4	732				
					1,244
5	834				
					1,181
6	895	948		860.6	
					1,150
7	929		919.6		
					1,055
8	945				
					991
9	949				
					845
10	942				

* Includes driver of truck being loaded, foreman of crew, and pickup labor.

Zwick and King took detailed time records of the pickup operation on broiler farms and reported their results under three headings: preparing to load, loading, and preparing to leave.[2] They used time records from 21 loads of poultry in the collection of which an average of six men was used and this crew went to the farm, loaded a truck, and returned. Their regression equations for each of the three activities were:

Preparation to load at farms:

$$M = 22 + 4.296X$$

Loading:

$$M = -33 + 52.382X$$

Preparation to leave farm:

$$M = 23 + 1.688X$$

Where:

M = man minutes
X = size of load in thousands of pounds

Combining all of these three straight line regression equations yields a productivity of 1,044 pounds per man hour. This does not include the

[2] *Competitive Position of the Connecticut Poultry Industry. 5. The Economic Advantage of Location in Marketing Live Poultry*, C. J. Zwick and R. A. King, Storrs Agricultural Experiment Station Bulletin No. 293, 1952.

time for personal needs specified for this study. So 40 minutes a day per man was added to the daily time which reduced productivity to 948 pounds per man hour, and is shown in Table D-1.

A final source of information on catching and loading birds is contained in a report by Jewett.[3] This research used empirical data and reported the amount of time for "loading" as distinct from travel and waiting as 3.4 man hours per 1,000 birds. Converted to pounds per man hour this is equivalent to 1,029. As with the Connecticut study, this productivity number included only actual loading time. Adding time for personal needs for the seven man average crew results in a productivity rate of 919.6 pounds per man hour. This is shown in Table D-1.

In Table D-1 the marginal productivity is shown in terms of pounds per hour. This was derived arithmetically from a function relating total crew productivity per hour to crew size. The marginal productivity drops irregularly from about 1,240 pounds per hour at the three to five man crew size and reaches 845 pounds at the nine to ten man crew size.

If loading time were the only consideration, a firm would not use a crew size smaller than that at which marginal and average productivity in loading are equal. Based on these data this would be nine men. In practice smaller crews are often used, and the crew size selected under some conditions in this study is smaller than nine men. This occurs because time in travel is also considered in selecting the optimum crew size in each situation.

---

[3] *Handling and Processing Broilers in Maine. Part 1. Costs and Efficiencies in Assembling Live Broilers for Processing*, Lloyd J. Jewett, Maine Agricultural Experiment Station Bulletin No. 592, 1960, p. 12.

APPENDIX E

Truck Ownership and Operating Costs [1]

Fixed Costs

Registration and bonding costs were established in relation to truck capacity by interpolating from information obtained on field schedules. License costs were established at $3 per vehicle, the typical value in New England. Cost of antifreeze, at $2 per gallon, was determined by radiator capacity and provision for temperatures of –30°F.

Federal excise tax has been included at $1.50 per year for 1,000 pounds taxable gross weight paid by registrant on truck combinations over 26,000 G.C.W.[2] Insurance rates for trucks of various sizes were interpolated from information on field schedules. Variation exists from state to state so modal values were used.

Fixed costs for trucks are summarized in Table E-1.

Table E-1. Fixed Cost Charges Per Year for 190 and 220 Crate Trucks.

Item	Capacity of Truck — Crates 190	220
	(dollars)	
Antifreeze	3	4
License	3	3
Registration	150	175
Bonding	60	80
Insurance	600	800
Federal Excise Tax		44
Total Annual Cost	*816*	*1,106*
Annual Cost Per Crate of Capacity	4.29	5.03
Cost Per Day*	3.30	4.48

* 247 operating days per year.

Variable Costs

As truck size increases the number of miles traveled per gallon of gasoline declines. On the basis of data obtained in the survey of assembly firms and from secondary sources, rates of performance for trucks per gallon of gasoline were set at seven miles for the 190-crate truck and six miles for the 220-crate truck.

Tire cost is a function both of time and wear. Records of assembly firms indicate that tires have a life span of six years due to deterioration and rot. Within that time limit, however, tread wears out in direct pro-

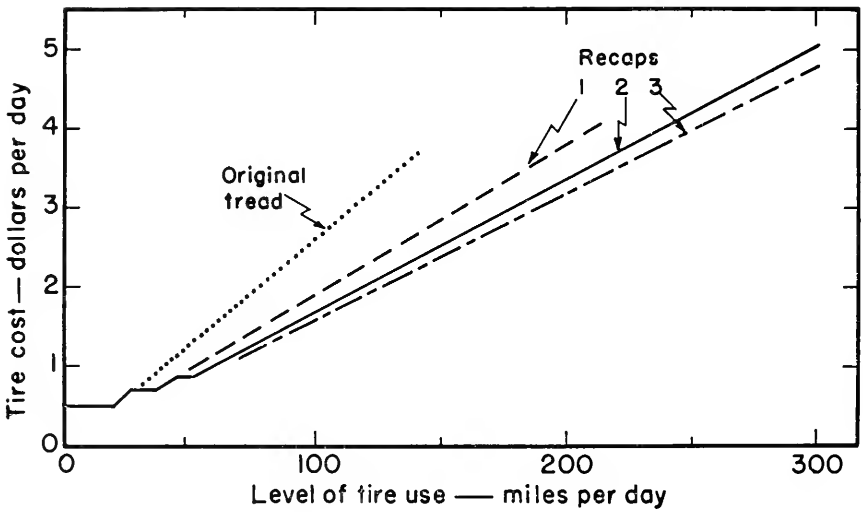
[1] Adapted from Rogers and Bardwell, op. cit.

[2] *Motor Truck Facts*, Auto. Mfgr. Assoc., Detroit, 1957 ed., pp. 28-33.

portion to use. Tread can be replaced through recapping many times. A maximum of three recappings is assumed in this study. Figure E-1 shows the change in costs with tire use per day for four tread conditions. As more recappings are applied the original tire cost is spaced over more miles.

Lubrication and oil change are carried out every 2,000 miles. This sets a constant cost per mile for the two combined of 0.413 cents for the 190-crate truck and 0.461 cents for the 220-crate truck.

Figure E-1. Tire Cost Per Day Relative to Daily Mileage of Truck.



Repair and Maintenance Cost

Repair costs depend primarily on truck size, age, and mileage operated. As truck size increases these costs increase, but not in proportion to capacity or price of truck. The larger the truck the higher the repair bill for any particular job.

For any particular truck size, repair and maintenance costs per mile tend to increase with miles traveled at an increasing rate until it becomes necessary to carry out a major overhaul or replace the motor. However, time depreciation affects repair and maintenance costs. A truck traveling 50,000 miles in one year is likely to have a lower repair bill per mile than one traveling 50,000 miles in five years.

In this study it is specified that trucks will be traded just prior to major overhaul or engine replacement. Based on data from assembly firms, dollar costs of repairs for each successive 10,000 mile interval were constructed for each truck size. The accumulation of these through each 10,000 mile interval until major overhaul or engine replacement occurred yielded the total repair cost.

For maintenance cost, the survey records indicated that regardless of age or mileage some maintenance was performed. This amounted to about one percent of new truck cost per year.

Repair and maintenance costs per mile are expressed by the following:

$$RM = \frac{C + (Y-X)\ .01N}{0}$$

Where:

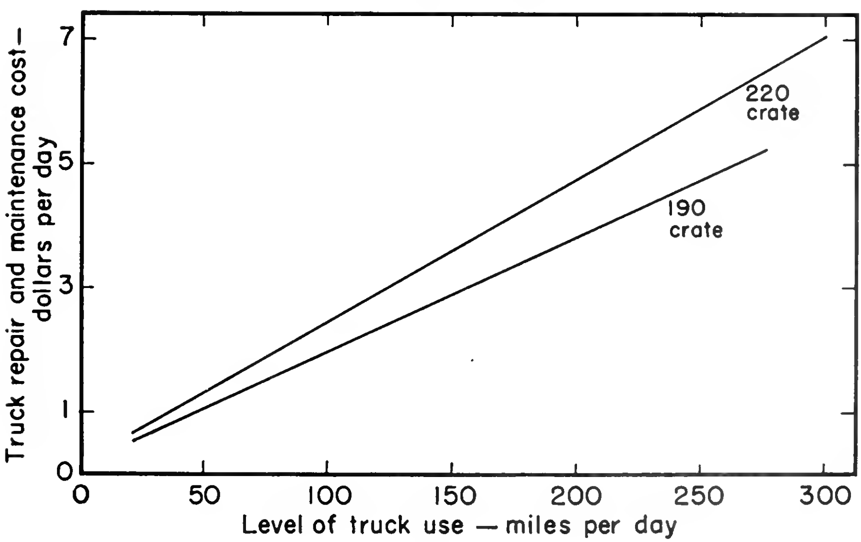
C = total repair cost
Y = number of years to major overhaul at A miles per year for specific truck
X = number of years to major overhaul at 10,000 miles per year
N = original price of chasis plus one-half original price of platform
0 = miles to major overhaul for size of truck

For different annual mileage levels Figure E-2 was constructed. Cost per day increases on a straight line although not proportionately as miles per day increases.

Table E-2. Value of Constants for Repairs and Maintenance Cost Equation for 190 and 220 Crate Trucks.

Truck Size	C	X	N	0
(crates)	($)	(years)	($)	(1,000 miles)
190	1,590	7	4,025	70
220	2,225	8	4,500	80

Figure E-2. Truck Repair and Maintenance Cost Per Day Relative to Daily Mileage.



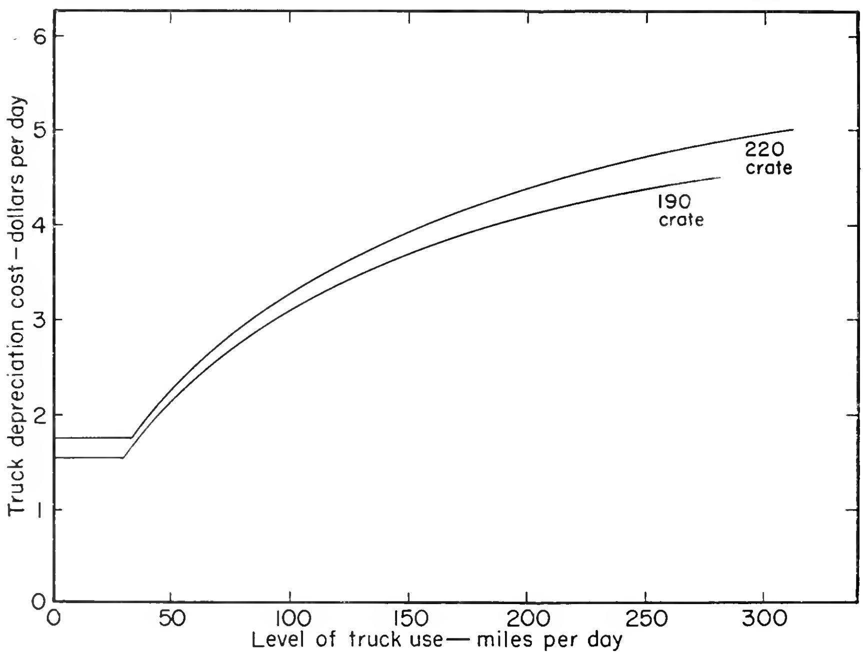
Depreciation Costs

A standardized list of truck values as percentages of original cost, by years of age, was derived by using published "book values" of trucks.[3] These are listed in Table E-3. Depreciation rates established by reference to automotive industry pricing are presumed to reflect "normal"

Table E-3. Trade-In Values and Depreciation Rates on Trucks.

Age	Trade-In Value Relative to Original Price at Beginning of Year	Annual Depreciation Relative to Original Price During Year
(years)	(percent)	(percent)
0		25
1	75	15
2	60	9
3	51	8
4	43	7
5	36	6
6	30	5
7	25	4
8	21	3½
9	17½	3¼
10	14¼	

Figure E-3. Truck Depreciation Cost Per Day Relative to Daily Mileage.



[3] *Official Automobile Guide*, Price Edition, Recording and Statistical Corporation, 87th ed., January 1958.

wear and time depreciation. It was specified that trucks would be traded every 10 years, or prior to a major overhaul or engine replacement. whichever occurs first.

Truck depreciation costs per day are plotted in Figure E-3.

Interest Costs

Annual costs were determined according to the formula used by Clarke and Bressler:[4]

$$I = (P-S)\ (r/2)\ (L + 1/L) + Sr$$

Where:

I = interest cost annually

P = original price of chassis minus tires: or original price of platform

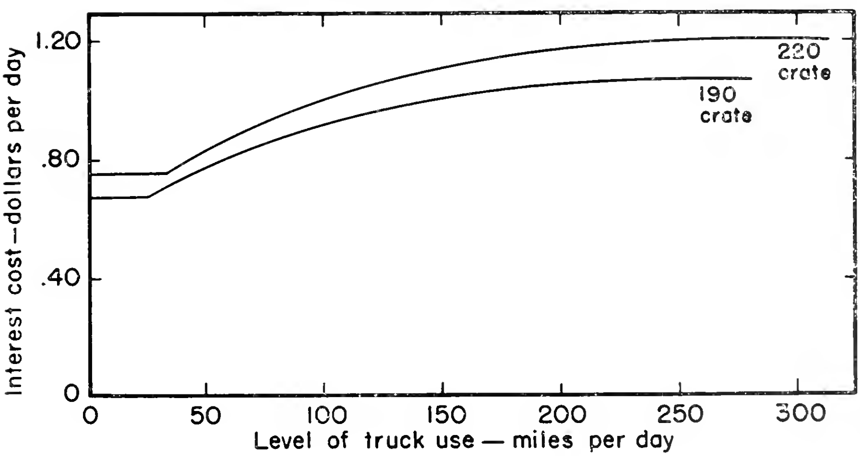
S = Salvage value of chassis at end of life (taken from Table E-3): or salvage value of platform

r = interest rate

L = O/A, years of expected life for chassis: or years of expected life for platform

O = miles to major overhaul for size of truck

Figure E-4. Truck Interest Cost Per Day Relative to Daily Mileage.

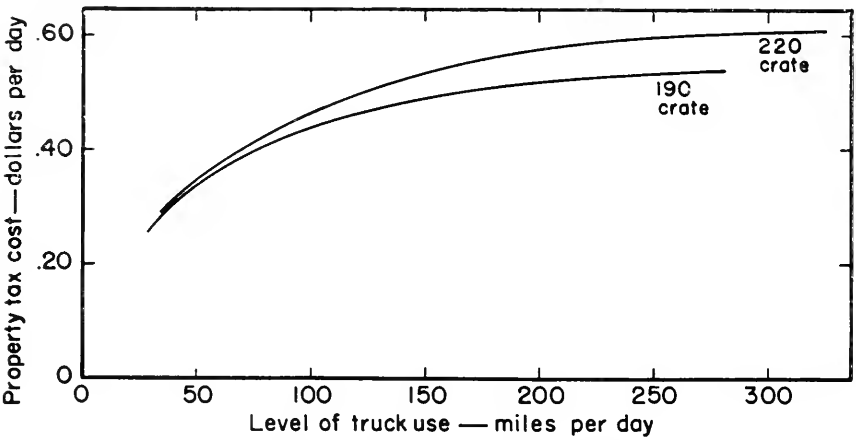


[4] D. A. Clarke, Jr. and R. G. Bressler, Jr., *Efficiency of Milk Marketing in Connecticut, 6. Truck Costs and Labor Requirements in Milk Delivery Routes*, University of Connecticut, Agricultural Experiment Station Bulletin No. 248, June 1943, p. 14.

Table E-4. Constants For Use in Interest Rate Equation.

		Size of Truck in Crates	
		190	220
Original Price, Chassis ($)	= P	3,600	4,000
Original Price, Platform ($)	= P	850	1,000
Rate of Interest (%)	= r	6	6
Miles to Major Overhaul (000)	= O	70	80

Figure E-5. Truck Property Tax Cost Per Day Relative to Daily Mileage.



Total interest charges for the platform were determined separately from the total interest charges for the chassis because they have different years of expected life, but these were combined into total interest cost for the vehicle. This interest cost was converted to a cost per day for the truck according to miles operated as shown in Figure E-4.

Property Tax Costs

The relative trade-in values listed in Table E-3 were used as the basis for calculating property tax. This was levied at the rate of three percent and was converted into a cost per day per truck as shown in Figure E-5.

Total Truck Costs

Table E-5. Summarized Costs for Truck Ownership and Operation Per Day, Other Than Gasoline, Oil, and Tires.

Cost Item	Truck Size 190	Crates 220
Fixed cost	3.30	4.48
Repair and maintenance cost	.70	.95
Depreciation cost	1.55	1.75
Interest cost	.67	.75
Property tax cost	.25	.25
Total	6.47	8.21

APPENDIX F

Table F-1. Method Used to Determine Location of Impound Point in Each Supply Band and Travel Time from Plant to Impound Points.

Firm	Annual Volume	Size of Supply Area	Radius of Firm Supply Area	Radius Added by Each Firm*	Supply Band	Radial Distance to Impound Point†	Road Distance to Impound Point‡	Travel Time 1-way to Impound Point§
	(million pounds)	(thousand sq. miles)	(miles)	(miles)		(miles)	(miles)	(hours)
			1,000 pounds per square mile per year density level					
A	4.15	4.2	36.4	36.4	I	25.7	33.2	1.33
B	12.45	12.5	63.0	26.6	II	51.4	67.9	2.30
C	24.90	24.9	89.0	26.0	III	77.1	102.6	3.08
D	34.58	34.6	104.9	15.9	IV	97.3	129.9	3.68
E	51.87	51.9	128.5	23.6	V	117.3	156.9	4.25
F	69.16	69.2	148.4	19.9	VI	138.8	186.0	4.87
			5,000 pounds per square mile per year density level					
A	4.15	.8	16.3	16.3	I	11.5	14.0	.63
B	12.45	2.5	28.2	11.9	II	23.0	29.5	1.22
C	24.90	5.0	39.8	11.7	III	34.5	45.1	1.75
D	34.58	6.9	46.9	7.1	IV	43.5	57.2	2.03
E	51.87	10.4	57.5	10.5	V	52.5	69.3	2.37
F	69.16	13.8	66.4	8.9	VI	62.1	83.7	2.62
			25,000 pounds per square mile per year density level					
A	4.15	.2	7.3	7.3	I	5.1	6.2	.32
B	12.45	.5	12.6	5.3	II	10.3	12.4	.58
C	24.90	1.0	17.8	5.2	III	15.4	19.3	.84
D	34.58	1.4	21.0	3.2	IV	19.5	24.8	1.05
E	51.87	2.1	25.7	4.7	V	23.5	30.2	1.25
F	69.16	2.8	29.7	4.0	VI	27.7	35.9	1.42

* Width of supply band.

† Full radius for previous supply area plus the distance into the added supply band of the average location of the birds. See Appendix A.

‡ Using linear equation Road Distance $= -1.534 + 1.351 \times$ Radial Distance for all radial distance greater than 10 miles and Road Distance $= 1.19635 \times$ Radial Distance for less than 10 miles.

§ From functions developed in Appendix B.

Table F-2. Number of Loaders, Foreman, and Drivers Required at Each Density Level for Bands and Firms.

Firm	Band	LOADERS Band	LOADERS Firm* S	LOADERS Firm* T	FOREMEN Band	FOREMEN Firm* S	FOREMEN Firm* T	DRIVERS (trucks) Band	DRIVERS (trucks) Firm* S	DRIVERS (trucks) Firm* T	TOTAL Band	TOTAL Firm* S	TOTAL Firm* T
						1,000 Pound Density Level							
A	I	3	3	3	1	1	1	2	2	2	6	6	6
B	II	5	8	8	1	2	2	3	5	5	9	15	15
C	III	11	19	19	2	4	4	5	10	10	18	33	33
D	IV	13	32	32	2	6	6	4	14	14	19	52	52
						5,000 Pound Density Level							
A	I	4	4	4	1	1	1	2	2	2	7	7	7
B	II	4	8	6	1	2	1	3	5	4	8	15	11
C	III	7	15	13	1	3	2	5	10	9	13	28	24
D	IV	6	21	19	1	4	3	4	14	13	11	39	35
E	V	12	33	31	2	6	5	8	22	21	22	61	57
F	VI	13	46	44	2	8	7	7	29	28	22	83	79
						25,000 Pound Density Level							
A	I	5	5	5	1	1	1	2	2	2	8	8	8
B	II	5	10	5	1	2	1	3	5	3	9	17	9
C	III	5	15	12	1	3	2	3	8	7	9	26	21
D	IV	4	19	15	1	4	2	3	11	8	8	34	25
E	V	9	28	24	2	6	4	4	15	12	15	49	40
F	VI	9	37	33	2	8	6	6	21	18	17	66	57

* S = loading each band separately — the diagonal of the matrix.
T = combining bands when feasible — the upper right hand portion of the matrix. These situations are the ones used in the development of costs in this study except in the case of the 1,000 pound density level where no combining was possible.

Table F-3. Number of Full and Partial Loads of Broilers to Handle Volume, and Number of Truck Trips Required, 190 Crate Truck, by Bands and Firms.

Band	Firm	Volume Hauled in Terms of Loads, 190 Crate Trucks Band	Volume Hauled in Terms of Loads, 190 Crate Trucks Firm	Truck Trips Required 190 Crate Trucks Band	Truck Trips Required 190 Crate Trucks Firm
		(loads)		(trips)	
I	A	1.68	1.68	2	2
II	B	3.37	5.05	4	6
III	C	5.05	10.10	6	12
IV	D	3.93	14.03	4	16
V	E	7.02	21.05	8	24
VI	F	7.02	28.07	8	32